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United States Agency for International Development
Environmental Training and Management in Africa

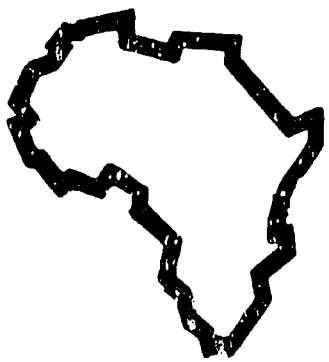
Workshop on

Land-Use Planning For Rural Development

With Special Attention to Environmental Management

Sierra Leone

1982



Land and Water Development Division
of
Sierra Leone Ministry of Agriculture and Forestry

Alabama A&M University
Huntsville, Alabama

South Eastern Consortium for International Development

Food and Agriculture Organization of the United Nations

FOREWARD

This workshop on Land Use Planning For Rural Development, with Special Attention to Environmental Management in Sierra Leone, is made possible by a process of close cooperative activities among a number of entities including the United States of America, Sierra Leone and the United Nations.

The Sierra Leone government was represented by officials of the Ministry of Agriculture and Forestry who actively participated in the planning of the workshop. Representatives of the South Eastern Consortium for International Development (SECID) and Alabama Agricultural and Mechanical University (AA&MU) played dominant roles in the organization and planning of the workshop, with vital assistance provided by the Food and Agricultural Organization of the United Nations (FAO/UNDP) staff.

Special recognition must be given to the United States Agency for International Development (USAID), without whose resources and input, this workshop would not have been possible.

E. N. M. Gooding, Ph.D. M.Litt (Oxon) Ph.D.
Alabama A & M University

INTRODUCTION

Sierra Leone, like many other nations of the developing world, is involved in the very vital process of long-range planning aimed at the development and effective utilization of its natural and human resources for the advancement of the welfare of the nation and the enhancement of the quality of life of its citizens.

This process of long-range planning must inevitably involve a model for rural development which would assure the proper and careful use of land and its related resources, and would contribute towards the maintenance of a balance between population growth and the demands that are placed upon the natural resources of the nation.

Towards this end, it is of importance that variables are factored into developing growth formulas that would contribute toward the protection of vital ecosystems of the nation, and the safeguard of its natural environment. By environment we refer to the physical, biological and social resource base within which development occurs.

The purpose of this workshop is to provide a forum on which policy makers and technicians in relevant departments of government that are involved in the process of planning and implementation of the long-range program of national development can come together. It is expected that through discussions and exchange of ideas, and through the formal presentation of papers and other means, that new understandings and insight will be gained into the problems and prospects, as well as the methods and means of application of land resource data in the

planning and execution of agricultural development programs and the managing of rural environment.

The papers, panel discussions, and other presentations cover issues ranging from rural land use planning techniques, remote sensing for multi-disciplinary land evaluation, to soil management and conservation, agro-ecological aspects of land use planning and socio-economic considerations of agricultural land use.

It is hoped that participants of the workshop will feel free to respond to issues, to make comments, to raise questions, and thus enhance the quality of the workshop as an educational experience.

Finallly, towards the end of the workshop participants will be able to contribute to an evaluation of the proceedings.

TO THE WORKSHOP PARTICIPANT

This workshop consists of welcoming remarks, keynote speeches, numerous technical sessions, summary comments, project field excursions, displays, evaluation mechanisms and this loose-leaf workbook. The workshop proceedings will be compiled at a later date and made available to the participants.

The material in this workbook is background material which has been specifically selected by the Alabama A & M University representatives to support the expected nature of some of the technical sessions. The material is arranged in the order of the Syllabus with blue separators between the five major technical session groupings.

The first grouping: "Multi-disciplinary Land Evaluation Techniques of Land Use Planning" is supported by articles on remote sensing, a land suitability mapping technique and two case studies of planning in Sierra Leone. The highway case (Blair, 1978) is interesting because it demonstrates the proper application of urban transportating planning principles and methods to a rural situation.

The second group of articles under the heading "Agricultural Aspects of Land Use Planning" introduces the reader of this document to some of the global as well as national issues relating to croplands, forests and rural planning.

The third grouping, "Aspects of Land and Water Management", includes articles which highlight two concepts with potential for broader application, one on water resources and two articles on alternatives to the sole use of pesticides.

The fourth grouping, "Socio-economic Considerations in Agricultural Land Use Planning", includes a larger collection of articles which presents issues on environmental costs of development, energy considerations, rural development methods and U.S. agricultural extension methods. A diagrametric manual for smaller wastewater treatment systems has also been included as information.

The fifth and last grouping of the related readings is presented under the heading of "Environmental Considerations in Land Use Plannning" and emphasizes natural environment issues. Concluding this section is a copy of an environmental assessment checklist which might be utilized as a guide.

The workbook also contains appropriate bibliographic material beyond that which might be found at the conclusion of each article, and extra note paper for your convenience. It is the hope of the workshop organizers that you take this workbook with you and make it a part of your professional working library.

Special Orientation and Alabama A&M University's Capacity to Participate in International Technical Assistance Efforts

Alabama A&M University is one of the oldest land grant universities in the U.S. and has achieved wide recognition for its teaching, research and public service activities during its 107 years of existence. The University is located in the Northern Tennessee Valley area of the State of Alabama within a county of strong agricultural heritage. The University is composed of the following: (1) School of Agriculture, Environmental Science and Home Economics, (2) School of Arts and Sciences, (3) School of Business, (4) School of Education, (5) School of Library Media, and (6) School of Technology. All of these schools offer graduate education as well as undergraduate studies.

Each of these schools has very strong departmental programs and in the School of Agriculture, Environmental Science and Home Economics, departmental programs are developed in the land grant tradition of research, teaching and extension. These departments--Food Science and Animal Industries; Natural Resources and Environmental Studies; Agribusiness Education; Community Planning and Urban Studies; Home Economics Education; Early Childhood Education; and Food and Nutrition--have well-trained and highly competent faculty whose experience in teaching, research and extension outreach activities is pertinent to the various developmental needs of the less developed countries.

Alabama A & M University has had a long-standing international involvement, particularly in the training of international students, most of whom are from less developed countries. The University has, thus through the years, gained a considerable insight and understanding of the problems and aspirations of such students and their people. At the moment the population of international students drawn from over 21 nations constitutes about 15% of the total enrollment at the University. A large proportion of these students are from African and several of the Caribbean Countries.

Administrative Structure

In addition to deans of schools, department chairpersons, and program directors, the University is administered by the president, executive vice-president and vice presidents for academic affairs and business and finance. These individuals serve as the top administrative body for the University.

Alabama A & M University maintains a specialized administrative structure to conduct its international development activities. The Office of International Programs at the University represents all of the academic departments and coordinates all the efforts of the University in technical assistance programs abroad. The Director of the Office reports directly to the University President. It should be noted that the technical staff required by this proposed program will be provided by the academic departments. These departments are committed to the program as currently envisioned, thus ensuring that field staff to be involved in the projects can be drawn from the

technical expertise and experience of the full staff resources of all relevant departments. The Office of International Programs at the University is able to provide logistical support, training program administration, instructional equipment and commodity purchase, and other services likely to be requested. This office provides administrative support of personnel in the field as may be required to execute any part of these programs.

Faculty Specialization and Availability

The University faculty is composed of well qualified, capable and experienced individuals, many of whom have lived and/or worked in developing countries. Many of them have thus had short and/or long term experiences in international work. Currently, we are involved in a number of development projects, for example, the Human Resources Development Project in Upper Volta where one of our faculty members served as Chief of Party and the Egerton Agricultural College Project in Kenya, where we provide technical staff for the African Training program at the school. We have collaborated with Purdue University in the planning of the Integrated Crop Protection (ICP) Collaborative Research Support Program (CRSP). We have had a faculty member visit the Cameroons and Upper Volta on a consultative basis to advise on the introduction of small grains such as triticale in those countries. Other faculty members have served in various other AID or FAO programs in the Philippines, Nepal, Nigeria, the Sudan, Haiti, and Costa Rica. At present, Alabama A & M University, jointly with

Purdue University, has received a USAID contract for the Niger Cereals Research Project. We are also a subcontractor to the University of Georgia in the Peanut CRSP planning program being responsible for the development of a global research plan in the areas of socioeconomics of peanut projection and utilization. Alabama A & M University is also a SECID colead institution in the Envoronmental Training and Management in Africa (ETMA) project. Also several faculty members served as members of the Phelps-Stokes Fund - American - Caribbean Linkage Exploratory Program in April of 1981.

In addition to and as a component of these institutional building activities, Alabama A & M University faculty members have guided a large number of field research projects and analyses with other host countries scientists, administrators, and students, some of which are in disciplinary areas which will be relevant for the achievement of goals desired in the proposed project. Examples are:

1. Since, 1976, some of the triticale adaptation research carried out at Alabama A & M University has been extended to and in collaboration with at least ten (10) countries on nearly all continents. Under such and other programs during the past few years, researchers from Tunisia, Upper Volta, Nigeria, Peru, Brazil, some Caribbean countries, Malaysia, Canada and Australia have visited our teaching and research facilities.

2. Alabama A & M has an expanding program in the remote sensing of agricultural and natural resources. For the past six years, it has studied practical problems of forest management, soil surveying, land use, transportation networks, and early disease detection using automated satellite imagery as well as conventional photointerpretation techniques.

3. Unique among its research programs is the work on winged-bean, a versatile tropical legume known for its food and nutritional value.

4. In 1974, Alabama A&M's food science program attained national acclaim by becoming accredited by the Institute of Food Technologists (IFT). It is the only accredited program of its kind among 1890 land-grant universities and one of very few in the southeastern United States. In accrediting this program, IFT considered the size and quality of the faculty, the physical facilities reflecting special interest orientation and capability in food science and technology. Alabama A & M's undergraduate and graduate programs in soil and plant science and timber management are also well recognized in the state and the region.

5. The rural sociology and agricultural education programs deal with various socioeconomic concerns that are at times overlooked in technical agricultural development programs. Studies of income distribution, manpower needs for rural development and public decision-making processes are conducted in support of their teaching and research effort. This department continues to supply a major portion of the state's vocational agricultural teachers.

6. The Division of Home Economics has impressive programs in teaching, research and extension. It emphasizes early childhood education, home economics education and food and nutrition. Emphasis areas also include clothing and merchandising, community nutrition, clinical and therapeutic nutrition, general nutrition and management. These programs are housed in excellent facilities. The ongoing research programs include studies in food preferences of pre-school children, the problems and solutions to garment fit, etc. The Division has actively participated in taking information related to food and food preservation, nutrition, clothing and textiles to the community via AAMU's extension program which is particularly directed towards low income inhabitants of 13 northern counties in Alabama.

Additionally, Alabama A & M's current involvement in biomass research, in the study of aluminum toxicity and plant adaptibility to acid soils, and in the use of slow release fertilizers provide sufficient evidence that the agricultural teaching, research, and extension programs are contributing markedly to the national needs.

10/1982

MULTI-DISCIPLINARY LAND EVALUATION
TECHNIQUES OF LAND USE PLANNING

1. "Soil Inventory From Digital Analysis of Satellite Scanner and Topographic Data"

2. "Methods for Generating Land Suitability Maps: A Comparative Evaluation"

3. "Some Constraints on Planning for Development in Post-Colonial Africa: A Concise Longitudinal Evaluation of the Sierra Leone Case"

4. "The Regional Impact of a New Highway in Sierra Leone"

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Soil Inventory From Digital Analysis of Satellite Scanner and Topographic Data[1]

R. A. WEISMILLER, I. D. PERSINGER, AND O. L. MONTGOMERY[2]

ABSTRACT

A soil inventory of Chariton County, Missouri was prepared using computer-aided analysis of Landsat multispectral scanner (MSS) data to determine how spectral soil maps produced by digital analysis of satellite MSS data can accelerate and improve the quality of the National Cooperative Soil Survey Program.

Landsat data collected on 15 Apr. 1974 were spatially registered at a scale of 24,000 and overlaid with ancillary data in the form of digitized township, watershed, and physiographic boundaries. The county was classified into 30 spectrally separable classes using computer-implemented pattern recognition techniques. Approximately 64% of the county was identified as bare soil and was classified into 14 spectrally separable soil classes. The remaining 36% was classified as forest, pasture, and close-grown crops.

The digitized boundary data allowed the computer to manipulate, compile, extract, and present spectral class information within topographic or political units. The physiographic boundaries were used to delineate three landscape positions of interest: (i) bottomlands, (ii) gently sloping uplands, and (iii) moderately steep uplands. These delineations allowed the computer to differentiate between spectrally similar soils which occur on distinctively different landscape positions. Spectral classes of soil were correlated with individual soil series and taxonomic classifications for both the bottomland and uplands units.

While a spectral classification of soils alone cannot distinguish between widely different soils exhibiting similar spectral responses, it can aid in identifying meaningful divisions of soils. By combining digitized ancillary data with MSS data, a more detailed delineation of soils can be provided as compared to information derived solely from MSS data. Further refinement of this technique will continue to increase the usefulness of satellite MSS data as an aid in soil survey.

Additional Index Words: remote sensing, soil survey, soil mapping, watershed management, ancillary data.

[1]This work was supported by the USDA-SCS (Missouri) under a Cooperative Agreement with the Agric. Exp. Stn., Purdue Univ. Journal Paper no. 6576. Purdue University, Agric. Exp. Stn. Received 10 Jan. 1977. Approved 27 June 1977.

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AS WE BECOME MORE AWARE that our natural resources are of a finite nature, a means must be developed to inventory these resources adequately and to monitor their use. Computer processing of satellite data provides the technology and the opportunity to observe, assess, evaluate, and monitor the environment in a time span and with instruments never before available.

One of our most valuable but most often abused natural resources is our soils. If in the future we are to feed, house, and clothe our ever expanding population adequately, it is critical that our soil resources be effectively managed. Modern soil surveys provide a rational means of determining the suitability potentials and limitations of varying soils to support agricultural production. In addition these surveys lend themselves to a scientific approach useful in many ways to land use and natural resource management programs.

Several states in the USA have undertaken accelerated survey programs to obtain this critical inventory of soil resources. However, soil mapping techniques are generally costly and time consuming. Thus, new remote sensing techniques are continuously being evaluated by researchers to determine where they are appropriate and applicable. Westin and Frazee (1) reviewed the characteristics of Landsat data and stated that these data are quite applicable to soil survey programs because of the following characteristics: (i) synoptic view, (ii) multispectral data collection, (iii) ability to collect temporal data, and (iv) the near orthographic aspect of the data.

The majority of the soil survey work conducted with Landsat data has been accomplished using photointerpretation of imagery to delineate soil associations (5,7,11,12,13,14,17). Limited work has been accomplished using a digital analysis approach of Landsat multispectral scanner (MSS) data as applied to soil survey (3,10). However, research to date has shown that a strong relationship exists between the spectral reflectance characteristics of soils and many of their properties such as texture, organic matter content, color, and moisture re-

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gimes (6,15).[3] The Third Earth Resources Technology Satellite Symposium (Agriculture, Forestry, and Range Resources) (4) reviews most of the photointerpretative and digital analysis literature.

This paper discusses a computer soils inventory project conducted in Chariton County, Missouri to determine how spectral soil maps produced by digital analysis of satellite MSS data in conjunction with ancillary data can accelerate and improve the quality of the National Cooperative Soil Survey Program.

STUDY AREA

Chariton County, Missouri was selected as the study site because (i) a completed soil survey (9) was available to which the computer inventory could be compared, (ii) soil and land use information was of importance to the SCS watershed management personnel, and (iii) the county was easily accessible for field work and verification.

Chariton County is located in central Missouri and covers an area of approximately 195,065 ha. It is bordered on the west and south by the Grand and Missouri Rivers, respectively. The soils of this area formed in deep loess and glacial till in the uplands and in alluvial sediments in the floodplains. Three major land resource areas cover the county: (i) Iowa and Missouri deep loess hills, (ii) Iowa and Missouri heavy till plain, and (iii) central Mississippi Valley wooded slopes. A large portion of the moderately steep upland areas is forested and the remaining area of the county is either in row crop, cereal grains, or permanent pasture.

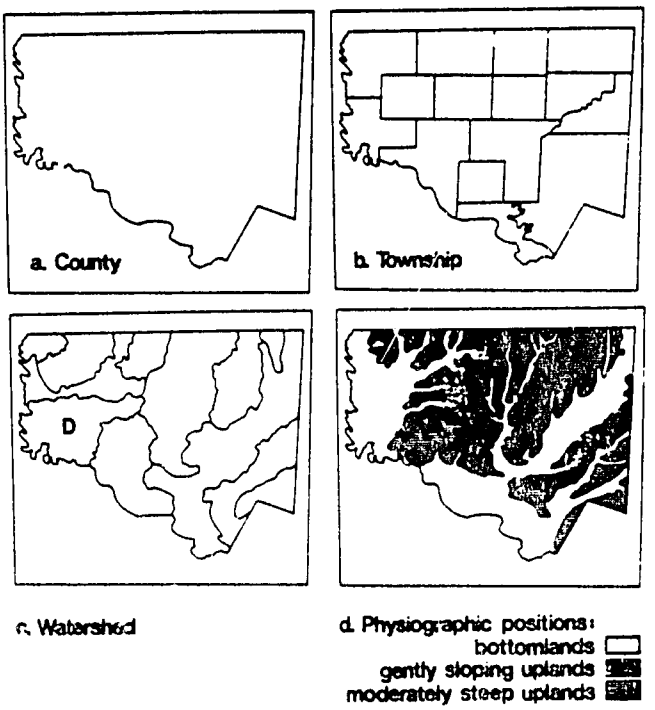

Fig. 1—Boundaries digitized and overlaid on Landsat-1 data.

DATA SET FORMULATION

Landsat-1 MSS data collected on 15 Apr. 1974 were utilized as the main data source for this study. This scene was selected because the data were (i) of high quality, (ii) acquired when most row crop cropland is in a bare soil state, and (iii) free of interfering atmospheric and surface conditions (i.e., clouds, haze, saturated soils, and standing water. Chariton County had received <13 mm (0.5 inches) of precipitation in the week prior to the Landsat overpass.

The Landsat MSS data were geometrically corrected (i.e., rotated, deskewed, and rescaled to an approximate scale of 1:24,000) (2). That portion of the scene containing Chariton County was selected for further preprocessing. These data were registered to ground control points selected from USGS 7.5 minute topographic quadrangles. This procedure produced a data set of an exact scale of 1:24,000 and registered geographic points in the data to their exact ground position. Using these same quadrangle maps, a number of topographic and political boundaries were digitized and subsequently overlaid and registered to the Landsat data. These boundaries included (i) county, (ii) township, (iii) watershed, and (iv) three physiographic position boundaries (bottomlands, 0-2% slopes; gently sloping uplands, 2-9% slopes; and moderately steep uplands, 9-20% slopes). Figures 1a, b, c, and d represent each of these boundaries, respectively. The resultant data set, thus, was limited to Chariton County and contained four channels of Landsat MSS data and three additional channels of data representing the township, watershed, and physiographic boundaries, respectively, at a scale of 1:24,000.

METHODS

Areas representative of the spectral nature of Chariton County were selected for input to a clustering algorithm program. This algorithm divided the MSS data into groups of sample points of similar spectral characteristics. A statistics processor was utilized to calculate the mean relative reflectance values and covariance matrices for each of these individual cluster groupings. Cluster groupings were either deleted, retained, or combined based upon their statistical separability characteristics. This procedure indicated that there were 30 spectrally separable classes within the study area. The statistics developed on each of these 30 classes were used by computer-implemented pattern recognition techniques and by a maximum likelihood Gaussian classifier to assign each of the data points to one of the 30 spectrally separable classes. This technique produced a classification results tape for the entire county. After classification, the ancillary boundary data were interfaced with the classification results tape to allow the extraction, manipulation, and presentation of results information within digitized topographic and/or political boundaries.

Of major importance was the ability to use topographic data (e.g., physiographic position) to separate soils which were spectrally similar but genetically different. This technique effectively increased the number of informational classes that could be extracted from the spectral data. Additionally, watershed boundaries allowed for the extraction and compilation of data within meaningful and manageable unit boundaries.

Alphanumeric 1:24,000 spectral maps and area statistics representing each of the 30 classes inventoried were produced for each of the 12 watersheds. Within each watershed, individual spectral maps and area statistics were produced for each of the three physiographic positions (i.e., bottomlands, gently sloping uplands, and moderately steep uplands).

Evaluation of the resultant inventory was conducted by Missouri SCS field personnel. The classification results printout was used to outline, at random, areas 16 ha or larger which were represented by the same spectral class symbol. All 14 of the spectral soil classes were represented in the 100 evaluation sites. These sites were located independent of the soil survey. After the sites were selected, the digital soils information was related to the soil survey, and a correlation between the soils spectral properties and their soil series designation was conducted.

[3] O. L. Montgomery. 1976. An investigation of the relationship between spectral reflectance and the chemical, physical, and genetic characteristics of soils. Ph.D. Thesis. Dep. of Agron., Purdue Univ.

Table 1—Information classes derived from digital analysis of Landsat-1 MSS data for Chariton County, Mo.

Informational class	Percentage of County area	Spectral classes per informational class
Bare soil	64	14
Pasture	16	4
Winter wheat	1	2
Forest	11	3
Other vegetation	<1	4
Water	7	3

RESULTS AND DISCUSSION

Thirty spectrally separable classes were contained within the inventory of Chariton County. The informational classes represented by these 30 spectral classes, the relative proportion of each, and the number of spectral classes contained within each information class is given in Table 1.

Table 2 compares the Landsat classification results with inventory data collected for Chariton County during the Conservation Needs Inventory (CNI) of 1970 (8) and a Missouri Department of Conservation, Forestry Division Inventory of 1974 (1). Since the Landsat data were collected in April, it was assumed that the 14 spectral classes of bare soil represented the area to be planted in summer crops. Thus, in this comparison the bare soil classes were equated to the corn and soybean classes of the CNI data.

Nearly 50% of the spectral classes describe 64% of the county area, e.g., bare soil (Table 1). The remaining spectral classes reflect similar proportions between the number of classes and the percentage of the county contained in these classes, indicating that they appropriately represent the desired informational classes. The inventory data presented in Table 2 lend further support to the validity of the Landsat inventory. The classes of hay-pasture, forest (all three classes), and water are in exceptionally close agreement with data collected by traditional means. The variances associated with the winter wheat; corn, soybean (bare soil); urban and federal lands classes are undoubtedly due to the nonuniformity of classes inventoried, changes in farming practices, and the variation in the total area included in each inventory.

Within the vegetated portions of the county, the spectral properties of the soils were not directly observable. In these areas little effort was made to relate soil cover to soil type. Thus, the 14 spectral classes which describe the areas existing as bare soil (64% of county) were of major importance in the soil inventory.

Digital mapping of soils using Landsat data is based solely upon the surface reflectance properties of the various soils. Such distinguishing soil characteristics as parent material, profile development, and landscape position are not observable with current satellite systems. Often widely different soils exhibit similar spectral responses and cannot be differentiated from one another using satellite data alone. However, appropriate ancillary data used in conjunction with the Landsat data can greatly increase the informational content of a spectral soils map.

Ancillary boundary data can be manually overlaid on Landsat data and the desired information extracted by visual means. Depending upon the amount of data being observed, this method often becomes quite burdensome and time consuming. However, if the ancillary data are supplied in a format such that the computer can accomplish the interaction of the two data sets, many of the manual problems are overcome.

Table 2—Comparison of land cover in Chariton County, Mo.

Informational class	Landsat data	Conservation needs inventory	Missouri Dep. of Conserv. For. Div.
	ha		
Corn, soybeans (Bare soil)	77,974	67,813	–
Winter wheat	8,079	11,997	–
Hay-pasture	58,735	60,451	–
Forest bottomland	13,786	–	13,703
Forest upland	12,522	–	12,643
Forest total	26,308	23,958	26,346
Water	2,465	2,362	–
Urban	–	5,125	–
Federal lands	–	4,320	–
Inventory total	184,951	176,026	195,065

Table 3—Distribution of informational classes for the Salt Creek Watershed,‡ Chariton County, Mo.

	Light colored soils†	Intermediate colored soils†	Dark colored soils†	Green vegetation	Forest	Water	Total
	ha						
Bottomlands	589	6,899	2,591	1,238	1,738	84	13,139
Gently sloping uplands	65	2,211	80	3,510	1,331	1	7,198
Moderately steep uplands	101	296	4	1,979	394	1	2,774
Total	755	9,405	2,675	6,727	3,463	86	23,111
Percentage	3.3	40.7	11.6	29.1	15.0	0.4	100

† Light, Intermediate, and Dark are subjective groupings of soils based upon their relative reflectance values.
‡ Watershed D, Fig. 1c.

As previously stated, four channels of digitized ancillary boundary data were registered to the Landsat data. These boundary data allowed the computer to manipulate, compile, extract, and present information within specific units. In this instance, physiographic boundaries were used to delineate three landscape positions of interest: (i) bottomlands, (ii) gently sloping uplands, and (iii) moderately steep uplands. The physiographic boundary data were used to allow the computer to differentiate between spectrally similar soils which occur on distinctively different positions in the landscape. The county, township, and watershed boundary data allowed for the presentation of information within desired political and geographical management units. Figure 2 and Table 3 illustrate the ability of the computer to interact the ancillary boundary data with Landsat data to present information extracted from subregions within the data set.

During field verification, the gently sloping and moderately steep positions were combined for convenience and considered as one physiographic unit, e.g., upland. Thus, the remainder of the discussion is limited to a bottomland unit and a combined upland unit. Tables 4 and 5 present the correlation of the spectral classes of soil with individual series and their taxonomic classification for the bottomland and upland units, respectively.

It is readily observable from Tables 4 and 5 that there is not a direct one-to-one correlation between spectral classes

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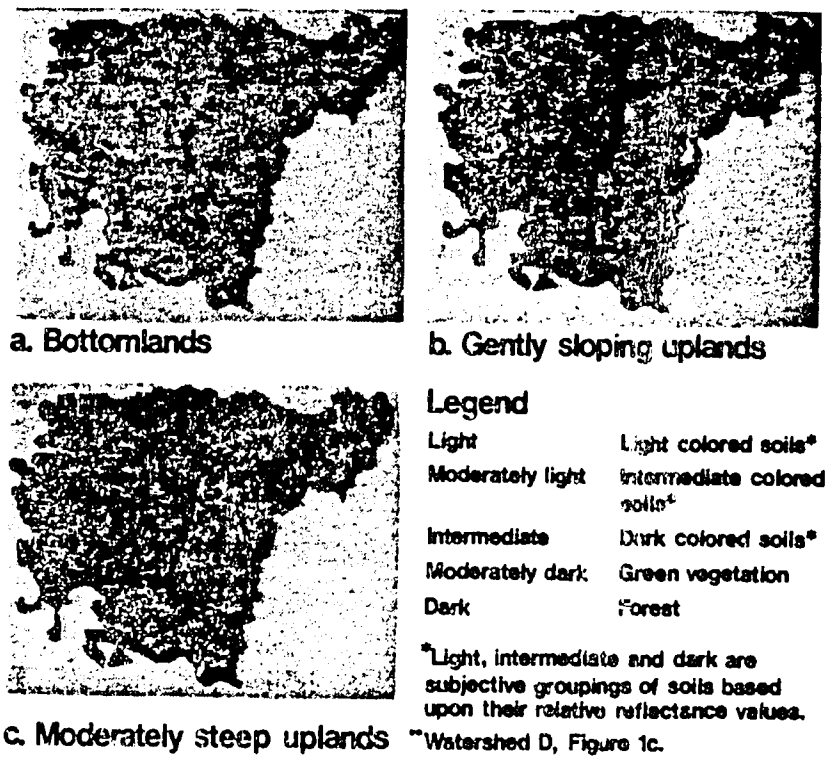

Fig. 2—Spatial distribution of informational classes for the Salt Creek Watershed, Chariton County, Mo.

and soil series or family. In some instances one spectral class may represent two or more soil series, and in other cases a single soil series may be represented by one or more spectral classes. In the bottomland unit all 14 spectral classes of soil were represented. These corresponded to 9 subgroups, 5 families, and 11 soil series (Table 4). In the upland unit, (Table 5) only 8 of the 14 spectral classes of soil were represented, corresponding to 5 subgroups, 2 families, and 7 soil series.

Table 4—Correlation and classification of bottomland units in Chariton County, Mo.‡

Spectral class	Soil series	Classification
		Fine, montmorillonitic, mesic
†A,C	Woodbury	Vertic Haplaquolls
B,D	Darwin	Vertic Haplaquolls
E	Bremer	Typic Argiaquolls
G	Chariton	Mollic Albaqualfs
I	Armstrong	Aeric Albaqualfs
		Fine-silty, mixed, mesic
F	Kennebec	Cumulic Hapludolls
F	Keg	Typic Hapludolls
H	Dockery	Aquic Udifluvents
		Coarse-silty, mixed, mesic
J,K,L	Haynie	Mollic Udifluvents
		Coarse-loamy, mixed, mesic
N	Ankeny	Cumulic Hapludolls
		Sandy, mixed, mesic
O	Sarpy	Typic Udipsamments

† Alphabetical letters represent bare soil. The spectral reflectance from the soil surface in general increases from A to O.
‡ The spectral class symbol was compared to the soil series on 100 sites that were 16 ha or more in size. The table shows the dominant soil series that occurred for each spectral class.

The six spectral classes which were represented in the bottomland but not the upland unit, correspond to classes A,B,C,D,E, and O. Classes A,B,C,D, and E exhibit rather low spectral reflectances and correspond to the Vertic Haplaquolls and Typic Argiaquolls. Class O has a rather high relative reflectance and corresponds to the Typic Udipsamments.

Classes F through N exhibit intermediate relative reflectance values and are common to both the upland and bottomland units. Soils within these two landscape positions which are spectrally similar can be separated into their appropriate families and series by using the physiographic position boundary data incorporated within the data set. These spectral classes correspond to the Typic and Cumulic Hapludolls, Mollic and Aeric Albaqualfs, and

Table 5—Correlation and classification of upland units in Chariton County, Mo.‡

Spectral class	Soil series	Classification
		Fine, montmorillonitic, mesic
†F,G,H	Grundy	Aquic Argiudolls
H	Lagonda	Aquic Argiudolls
I	Edina	Typic Argialbolls
I	Gorin	Aquic Hapludalfs
J,K,L	Ladoga	Mollic Hapludalfs
L	Menfro	Typic Hapludalfs
		Fine-loamy, mixed, mesic
N	Lindley	Typic Hapludalfs

† Alphabetical letters represent bare soil. The spectral reflectance from the soil surface in general increases from F to N.
‡ The spectral class symbol was compared to the soil series on 100 sites that were 16 ha or more in size. The table shows the dominant soil series that occurred for each spectral class.

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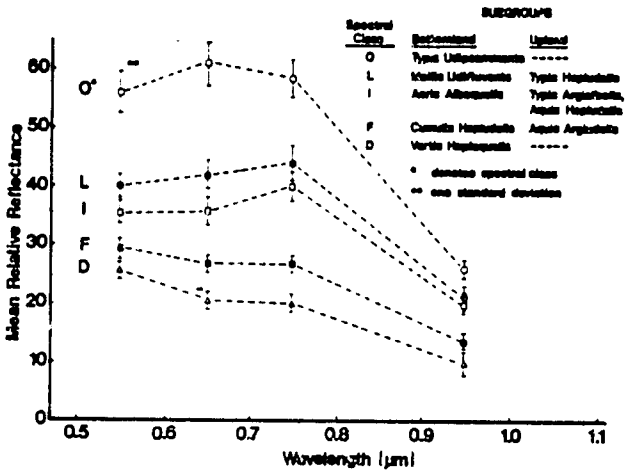

Fig. 3—Landsat relative reflectance values for representative spectral soil classes.

Mollic and Aquic Udifluvents in the bottomlands and the Aquic Argiudolls, Typic Argialbolls, and the Aquic, Typic, and Mollic Hapludalfs in the upland areas.

To illustrate quantitatively the spectral separability of soils, the mean relative reflectance values for five representative soils were plotted against their respective Landsat spectral band (Fig. 3). In all cases the mean values are distinctly separable, and when represented in standard error form, the intervals overlap in only two instances.

CONCLUSIONS

The conventional differentiation of soils at the subgroup, family, and series level is based upon both surface and subsurface properties. As previously stated, computer mapping of soils using Landsat MSS data is based solely upon the reflectance of the soil surface layer. However, multispectral data collected by Landsat have the unique characteristic of containing information from both the visible and reflective infrared portions of the spectrum and contain information not available in black and white aerial photography or visual observations. These data can provide valuable information to the soil survey since there is a strong relationship between the spectral reflectance of soils and certain soil properties important to soil classification.

While a spectral classification of soils alone cannot distinguish between widely different soils exhibiting similar spectral reflectances, it can aid in identifying meaningful divisions of soils. By combining digitized ancillary data with MSS data, a more detailed delineation of soils can be provided than can be derived solely from MSS data. This study utilized digitized topographic boundaries for the separation and presentation of spectrally similar soils by landscape position, e.g., bottomlands and uplands. This technique effectively increased the informational content of the 14 spectral classes of soils to describe 14 subgroups, 7 soil families, and 18 soil series classes.

A priori knowledge of the location and areal extent of soils subgroups, family, and series, as derived from digital analysis of satellite MSS data, is especially important in developing a soil survey legend. This information can also be very helpful in locating typical homogeneous soils in sampling for laboratory analysis. By utilizing spectral soil maps in combination with appropriate ancillary data as overlays on field mapping sheets (aerial photography), soil scientists in the field can be expected to improve the accuracy of their soil boundary placement techniques.

This additional knowledge of soils should greatly increase the efficiency of the overall soil survey effort. Further refinement of these techniques and the inclusion of other pertinent ancillary data (i.e., parent material boundaries) will continue to increase the usefulness of satellite MSS data as an aid in soil survey.

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Methods for Generating Land Suitability Maps: A Comparative Evaluation

Lewis D. Hopkins

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Land resource inventories to determine land suitabilities have become a standard part of planning analysis at many scales. Any attempt to review, compare, evaluate, or improve upon the myriad of case studies, many only partially documented and in limited circulation, suffers from the lack of reference to a common framework. This article develops a general statement of the purpose and character of land suitability analysis, a taxonomy of existing methods for identifying homogeneous areas and rating them as to suitability for specific uses, and a comparative evaluation of these methods.

A suitability map shows the spatial pattern of requirements, preferences, or predictors of some activity. Although the use of the word suitability is often restricted to analyses related to development, the analytical concepts involved are much more general. Using the word loosely, a suitability map for natural hazards (Patri, Streatfield, and Ingmire 1970) identifies the pattern of and characteristics associated with some hazard, such as earthquakes. A suitability map for vulnerability to impact (Murray, et al. 1971) shows the pattern of characteristics that portend varying degrees or likelihoods of damage from some action elsewhere. For example, low lying lands near flood plains are vulnerable to flooding if there is additional development upstream. Suitability maps for natural hazards, vulnerability to impacts, or off-site impacts are usually preliminary steps in the development of suitability maps for the location of land uses, which might range from nature preserves to nuclear power plants. All of these applications of suitability mapping rest on the same general analytical base. The methods described here might be applied to any of them. For simplicity in this article, most of the discussion focuses on land use rather than in terms of hazard, vulnerability, or impact.

Determining the levels of particular costs or impacts is not the central issue here. The primary issue is how such cost or impact information can be manipulated and combined to generate suitability maps for land uses. In this article *suitability* will be assumed to include market, nonmarket, and nonmonetary costs and impacts. The difficulties in obtaining such measures in practice, of course, remain; but discussing these difficulties simultaneously would muddle the attempt to distinguish among methods for generating suitability maps. MacDougall and Brandes (1974) provide a bibliography covering many of the aspects of land resource analysis not covered in this article.

The output of a land suitability analysis is a set of maps, one for each land use, showing which level of suitability characterizes each parcel of land. This output requirement leads directly to two necessary

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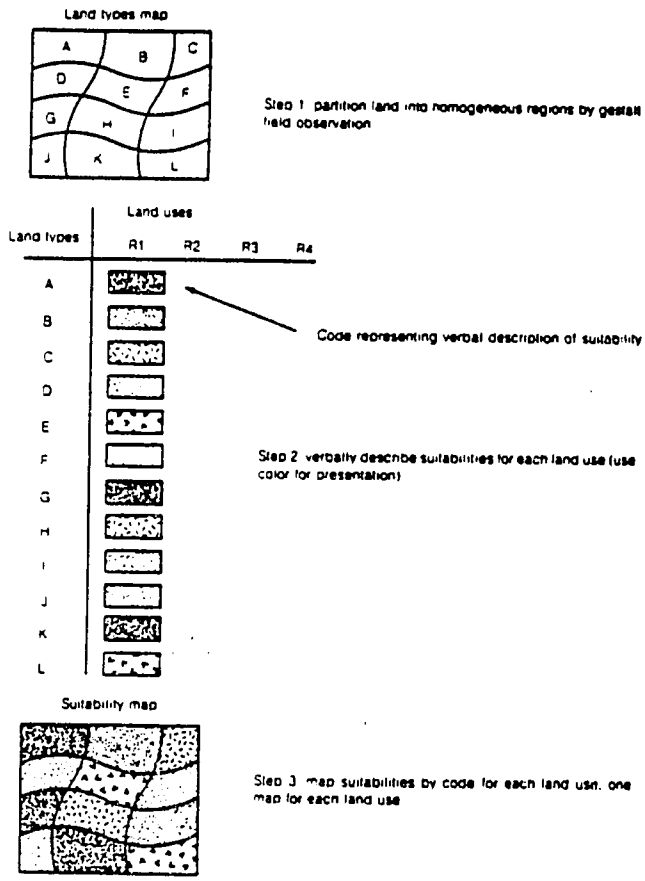
Figure 1. Gestalt method



components of any method: (1) a procedure for identifying parcels of land that are homogeneous and (2) a procedure for rating these parcels with respect to suitability for each land use. The next section describes a method in which each of these components is carried out directly without any consideration of the factors that determine the homogeneity of regions and the suitability of land uses. This method sets the stage for considering other methods that explicitly combine factors.

Gestalt method

The essence of the gestalt method is that the homogeneous regions are determined directly through field observation, or perhaps aerial photographs or topographic maps, without consideration of individual factors such as slope, soils, vegetation, and so on. A gestalt is a whole that cannot be derived through consideration of its parts. A strict interpretation of gestalt would mean that individual factors that could be manipulated to provide understanding of the whole do not even exist.

The gestalt method of suitability analysis can be described in three steps and is diagramed in Figure 1. First, the study area is partitioned by implicit judgment into homogeneous regions, such as uplands and valley floors. Second, a table is developed that verbally describes the effects or problems that will occur in each of the regions if each of the potential land uses is located there—e.g., this region presents no construction problems, but has no amenities that would render it a pleasant place in which to live. Note from Figure 1 that some regions identified in step 1 may be determined in step 2 to be of equal suitability for some uses, because the homogeneous regions in step 1 are based on perceived natural land types, not on suitabilities for any one land use. Third, a set of maps, one for each land use, is drawn to show the homogeneous regions in terms of their suitability. Graphic presentation of the map requires that each descriptive suitability comment be represented by some color or symbol as in Figure 1.

It can be argued that any land suitability analysis must rely on gestalt judgments at some level of specificity. For example, vegetation cover types might be observed in the field and noted on aerial photographs. The determination of cover type is thus based on implicit judgment rather than on explicit rules. Cover types can be thought of as a combination of various lower level factors—age, understory species, canopy species, and management practices. In this case, a gestalt method is being used to generate vegetation cover type, a factor to be combined with other

factors in a later step. Once a factor such as cover type is identified, however, one can no longer use the gestalt method at some higher level because by definition it does not combine factors. Thus, although the gestalt method may underlie any other method at the elemental level, in this article gestalt method refers to attempting to determine land suitability directly in one gestalt judgment.

Limitations of gestalt method

Few people have the capability, and planners seldom have the longstanding local experience, to deal with land classification and interpretation as a gestalt. Some land resource inventory processes are specifically intended as a means of immersing the planner in a study region, "understanding the place" as McHarg (1969) calls it, so that gestalt judgments can be made. However, land suitabilities generated without identification of the factors considered are difficult for other people to scrutinize or confirm. The results are therefore difficult to communicate convincingly to decision makers.

Given both the scarcity of people capable of using the gestalt method and the frequent necessity of communicating results in public forums, more explicit methods must be found for generating land suitability maps. More explicit methods inherently require the consideration of factors—the variables or dimensions such as soils, slope, vegetation, and existing land use—that enter into the determination of suitabilities. The remainder of this article is concerned with how such factors can be combined in relatively explicit ways to yield land suitability maps.

Two early land suitability studies demonstrate the evolution from the gestalt method toward more explicit procedures. Hills (1961) devised a system of land types so that homogeneous regions, observable as gestalts in the field, could be grouped or partitioned to various levels of specificity for various planning tasks. Realizing that identifying homogeneous regions or natural land types as gestalts was a rare skill. Hills also devised a numerical rating scheme so that less-skilled personnel could derive land type regions from individual factors. The "weights" in Hills's rating scheme were fitted so as to replicate the suitabilities obtained by the gestalt method. The assumption was that the gestalt method yielded correct results. The only interest in the numerical rating scheme was that it could be used by less-skilled personnel and could be forced to yield the same results as obtained through a gestalt method.

The early work of Lewis (1969) can be viewed as testing a hypothesis that river corridors, which are readily observable as gestalts on aerial photographs or topographic maps, are excellent surrogates for regions of high cultural and scenic amenity. River corridors are indeed good surrogates, especially in glaciated midwestern landscapes. Once this hypothesis was confirmed, statements could be made about the suitability for various uses of the river corridor without mapping and explicitly combining the individual cultural and scenic elements each time a suitability analysis was conducted.

Another general response to the difficulties of applying gestalt was to devise explicit methods of combining factors in order to *discover* suitabilities. The assumption in this case is that the method yields valid suitability ratings because of the properties of the method itself. The results are not judged by conformation to some gestalt or empirical standard. This general approach was the one taken by McHarg. The ordinal and linear combination methods presented in the next section are generally perceived from this perspective.

Determining suitabilities by mathematical combination

This section describes three general methods for generating suitability maps by mathematical operations. These operations simultaneously identify homogeneous regions and determine suitability ratings.

Ordinal combination method

The ordinal combination method, sometimes referred to as the McHarg method because of its use in the Richmond Parkway study (McHarg 1969), is diagramed in Figure 2. The first step is to map for each of a set of factors (e.g., soils, slope, vegetation, land use) the distribution of types (soil types, slope classes, vegetation types, land use types). Factors are distinct dimensions along which variations among parcels of land can be described. Types are nominal labels for particular characteristics along a particular dimension (e.g., Drummer soil). The first step is illustrated in Figure 2 using one factor with three types and a second with four types. An actual study would include many factors and more types of each, but such expansion leads only to confusion for the purposes at hand.

The second step consists of filling in a table that indicates (in this case by levels of gray) the relative suitability rating for each land use of each type (e.g., soil type) of each factor (e.g., soils). The ratings assume consideration of all the characteristics of the type (e.g., for soil type this might include permeability, productivity, water table, etc.) and all the costs and impacts of the land use if located on this type. These ratings may be derived through use of other tables, maps, and extensive study (see, for example, Lyle and von Wodtke 1974), but the process of deriving them is not the central issue here.

The third step consists of making a suitability map

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for each land use based on each factor. For each land use the type designations on each factor map from step 1 are replaced with the appropriate gray levels from the particular land use column in the table from step 2. Step 3 is illustrated in Figure 2 for land use R1.

The fourth step consists of overlaying, for each land use, the suitability maps of individual factors. A composite suitability map is thus obtained for each land use. Each of these composite maps shows the spatial pattern of levels of suitability for the given land use.

Limitations of ordinal combinations. By describing the same process using a numerical index to represent gray levels some assumptions emerge that implicitly underlie the ordinal combination. Figure 3 is identical to Figure 2 except that gray levels have been replaced by an equivalent ordinal number system, an ordering of types for each factor. Step 4 in Figure 3 involves the addition of what appear to be numbers on an ordinal scale. This addition is an invalid mathematical operation in the sense that the mathematical properties usually assumed do not hold.

It is possible to manipulate numbers using any set of rules one might concoct; the point is, however, that one must be careful not to assume the usual mathematical properties when the required conditions are not being met. For the above described procedure to be valid in the usual system of arithmetic operations, the numbers must be assumed to be on an interval scale, such that the distances (intervals) between various ranks are equal. Further, the numbers assigned to the types of each factor must be assumed to be numbers in the same interval system, meaning the units used to measure intervals of suitability must be the same. Before considering modifications to handle these inapplicable assumptions, it may be helpful to read the appendix, which establishes some frequently cited, but still frequently misunderstood, characteristics of alternative measurement systems.

Because the operation of overlaying maps in the ordinal combination method is equivalent to addition, an assumption that the ratings of each factor are independent is also implied. This method cannot deal with the situation where the relative suitability for a particular use of a given soil type depends on the slope type with which the soil type occurs. A slope of 25 percent occurring on well-drained soil over clay might be quite disastrous for high cost residential development, as demonstrated in California, and therefore receive a low rating. At the same time, a slope of 25 percent and well-drained soil on a dif-

Figure 2. Ordinal combination method with gray levels

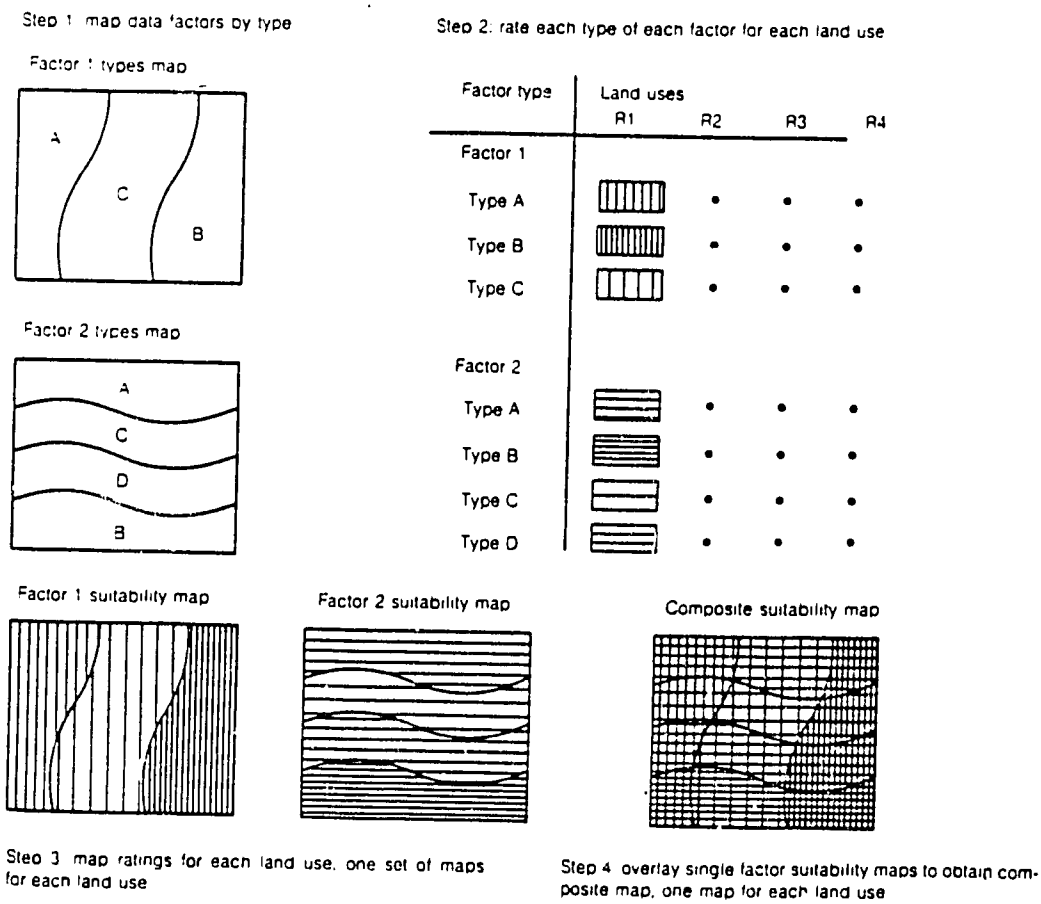
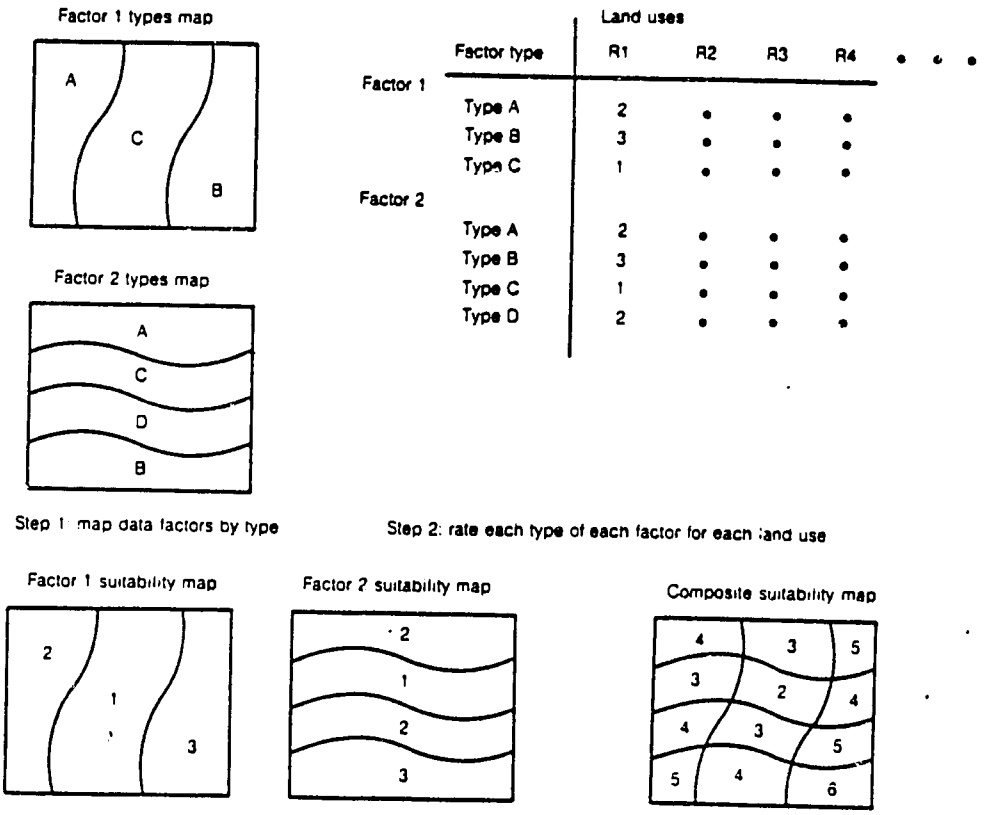


Figure 3. Ordinal combination method with numerical index



ferent subsurface or a slope of 5 percent on well-drained soil over clay might be quite acceptable. The suitability may be a nonlinear and nonseparable (i.e., multiplicative) function of the combination of types; it is not, in general, simply the sum of the suitabilities of the individual types.

Ordinal combination is *not* a good method for generating suitability maps because of the implied addition of ordinal scale numbers and because of the implied independence of factors.

Linear combination method

The most frequent response to this understanding of the measurement assumptions of the ordinal combination method has been to play the weighting game. The usual procedure is illustrated in Figure 4. The types within each factor are rated on separate interval scales. Then a multiplier—often identified as an *importance* weight—is assigned for each factor as shown in step 2. The ratings for each type are multiplied by the weight for the factor. The suitability rating for a particular region is then the sum of the multiplied ratings, or in mathematical terms, the linear combination. The effect of multiplication by the weights is merely to change the unit of measure of the ratings on each factor by the ratio of the multipliers so that all of the ratings are on the same interval scale (e.g., if one factor is in dollars and another in cents, then the first would be multiplied by 1 and the second by 0.01 to put both in dollars). The ratings can then be added. Thus, the units of measure for suitability with respect to each factor can be made equivalent after rating the types for each factor individually on interval scales with different measurement units.

Rating procedures. A straightforward explanation of the linear combination method is given by Ward and Grant (1971), although (or because) the example is entirely artificial as is the one here. Each type of each factor is assigned an interval rating from one to nine, where nine is most preferred. Each of the factors is then assigned a weight. The information is then combined by the standard formula for a weighted average: the sum of the products of the ratings multiplied by the respective weights for each factor, divided by the sum of the weights.

$$\text{Rating} = \frac{w_1 r_1 + w_2 r_2 + \cdots + w_n r_n}{w_1 + w_2 + \cdots + w_n}.$$

A *1* is the minimum rating permitted in the Ward and Grant example, suggesting that a system visualized as ordinal is being scaled by multiplication and addi-

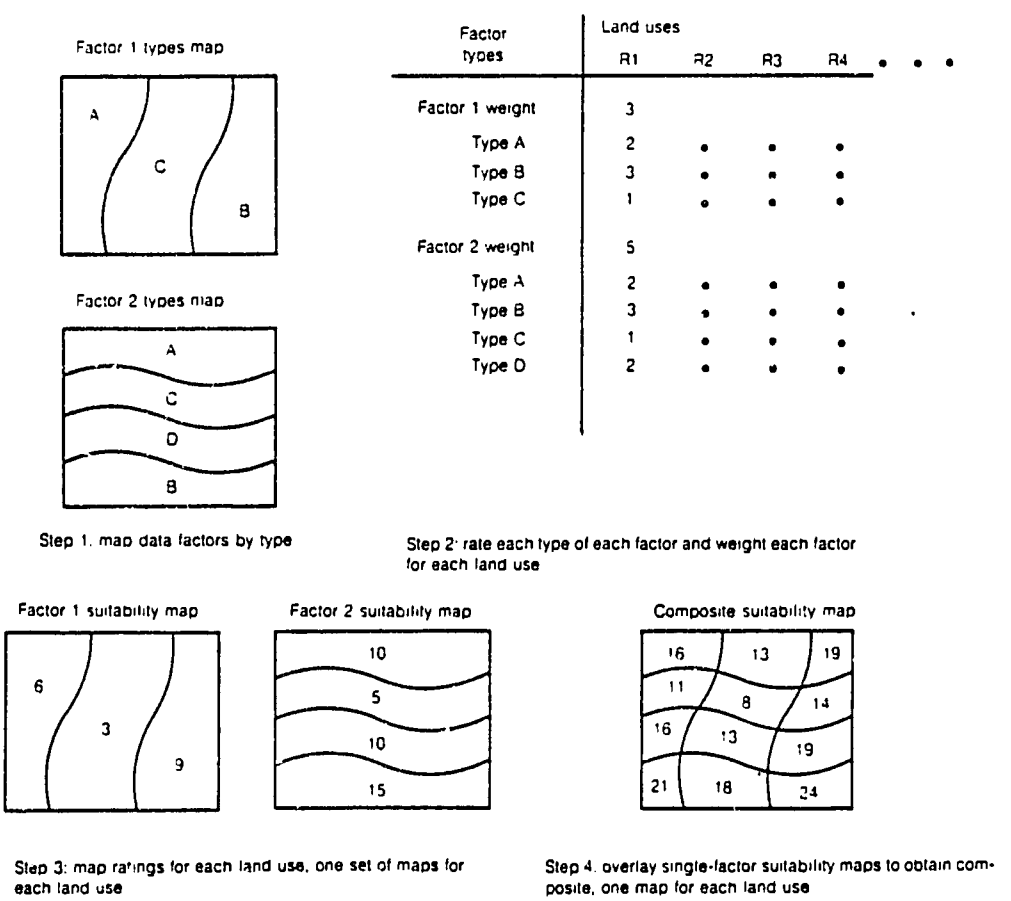
tion. One therefore must assume, as is indicated implicitly, that I represents zero, and signifies no amenities and all costs (see appendix). The weights are merely relative proportions among the units in which the suitability within each factor was measured in the first place. One must be wary of using units of measure resulting in single factor ratings of 4, 6, and 8 with an importance of 1, versus ratings using units resulting in 2, 3, and 4 with an importance of 2. This ambiguity occurs in the Ward and Grant example. The importance weights are not independent of the units used to measure suitability in terms of the individual factors.

Another alternative is to transform the set of rating values for each factor to a range that is common for all factors. For example, a transformation of the form $r_i' = r_i/r_i^{max}$, where r_i^{max} is the maximum rating for any type for factor one, would transform all ratings for the factor to the range zero to one. This transformation expresses the ratings in an interval unit that makes all factors equally influential in determining the resultant variation in suitability among regions. This transformation makes the use of importance weights more comprehensible in that it eliminates any differences attributable to the unit of measure used for a particular factor. It is then possible to (re)introduce these differences through importance weighting without the ambiguity found in the Ward and Grant example.

Another rating scheme, which is equivalent to a linear combination, is familiar to many as a method frequently used in grading examinations. First, a total possible suitability (test score) of 100 is divided among various factors (questions) so each is worth a certain proportion of the total. Each type (answer) of each factor (question) is then rated as to its suitability (quality) relative to the proportion of the total score assigned to the factor (question). For example, one might assign (receive) a 7 out of a possible 10 on a factor (question). The scores for each factor (question) are then summed to get a total score for a site (exam). The total score is usually expressed as a percentage of the maximum possible score. This procedure has been proposed for environmental impact assessment (Battelle 1971). A procedure based on the proportional scoring concept is also used by Lyle and von Wodtke (1974).

The result of the weighted combination is a single measurement scale with a common unit. Some people find it easier to evaluate all the types of all the individual factors directly in a common unit rather than devising separate units of measure and weights

Figure 4. Linear combination method



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operationalization of the planning process needed serious revision in pre-independence Sierra Leone. We will proceed to investigate whether these deficiencies were rectified in the subsequent development plans.

Post-independence planning

Saylor, writing six years after Sierra Leone's independence, commented on the viciousness of the external orientation of the economy (9). Noteworthy, are his observations that unlike most tropical African countries such as Senegal, Ghana, Mali, Guinea and Tanzania, Sierra Leone:

> had not modified its traditional or inherited capitalistic institutions to any marked degree.

He was also critical of the role being played by British commercial banks in the veritable underdevelopment of the country through exploitation (10):

> ... the commercial banking has served as a mechanism for funneling savings into Great Britain and away from Sierra Leone.

Deliberate discrimination practices in money-lending and its role in underdevelopment was also exposed. Saylor pointed out that these British-controlled banks never extended loans to potential Sierra Leonean entrepreneurs and thus served as an effective brake to participation by the indigenes in modern commercial enterprising.

As in the case of Cox-George, Saylor noted lack of serious integrative contemplation regarding each of the national development plans right from the mid-forties to the early seventies (11):

> ... each of the plans formulated for Sierra Leone is essentially an *ad hoc* capital budget designed to achieve either [1] the construction of a limited number of isolated public goods or [2] the attraction of foreign aid.

According to Saylor several operational shortcomings have also neutralized past Sierra Leone's National Development Plans, the major ones being (12):

1. No timing or continuity is maintained between successive Plans.
2. Comprehensive economic planning in the sense of absolute control over the allocation of resources has never been attempted or contemplated.

(9) *Ibid.*, Cox-George, p. 3.
(10) *Ibid.*, Saylor, p. 176.
(11) *Ibid.*, Saylor, p. 159.
(12) *Ibid.*, Saylor, p. 159.

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3. Planning agencies have not attempted to formulate a consistent set of quantitative goals amenable to available sets of instruments.

4. The plans have been stated in general normative terms as targets, thus they tend to be non-operational.

This study would be incomplete without examining the most recent National Development Plan, to which we now turn.

Contemporary planning

The preceding remarks constitute a background against which the 1974/75 - 1978/79 National Development Plan (13) can be better analysed. Basically the current Plan embodies the aspirations of a state with a mixed economy (p. 31) which is desirous of fulfilling socialist-oriented role (social justice, p. 99). That in itself, from past experiences, is an impossible task. However, that should not deter us from proceeding with the analysis of some of the Plan's attributes for the moment.

Evidently, the need for "coverage, accuracy and timeliness of statistical information" noted earlier by Cox-George is still lacking (p. xi). A classic example of this is the absence of comprehensive soil and land capability data (p. 13). Whilst this shortcoming is realized there is no substantive evidence of its rectification in the Plan.

As before, "the greater part of the modern sector of the economy has remained under foreign ownership" (pp. 1, 7). Consequently, this has crippled potential economic growth because of a massive repatriation of profits from the country (see Table 1). The dysfunctional role of British exploitation and discrimination in money-lending institutions is very much alive.

> Commercial bank credit is largely concentrated at present on commerce, especially the financing of imports (p. 37).

How to bring the small indigenous entrepreneur into the picture is as mysterious as it is elusive in a mixed economy with British capitalist monopolies having the final say on who does or who doesn't get financed.

A welcome change is the realization that increased government role in the mobilization of both the private and public sector is essential in the implementation of the Plan:

> The Government must assume an overwhelming part of the burden of translating the objectives of the Plan into reality (p. 33).

(13) *Ibid.*, National Development Plan, Sierra Leone.

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Three basic problems are apparent in the actualization of the plan. First, most of the objectives are stated in normative, non-measurable terms (see Ch. 9 and Ch. 10). Secondly, the principle of a mixed

TABLE 1. — *Investment and profit expropriation in Sierra Leone*

Year	Total Direct Foreign Private Investment (Le million)	Investment Outflow Profits, Dividends Fees, etc. (Le million)	1963-72 Net Outflow (Le million)
1963	7.3	9.7	2.4
1964	8.8	10.7	1.9
1965	12.1	12.3	0.2
1966	4.9	8.9	4.0
1967	4.5	10.4	5.9
1968	5.8	11.7	5.9
1969	13.5	11.9	1.6
1970	6.9	9.8	2.9
1971	4.4	8.4	4.0
1972	3.0	7.4	4.4

Source: 1974/75 - 1978/79 National Development Plan (p. 6).

economy is strongly espoused (p. 31) thus leaving the Plan open to conflicting foreign and local interest groups. Thirdly, although the government is assumed to be responsible for translating the plan into reality:

> The administrative machinery of the government is not presently fully equipped to assume a leading role in the process of economic and social development (p. 33).

Finally, and perhaps more seriously, the financing of the Plan is heavily dependent on foreign sources (pp. vi, ix, x, xi, 21, 33-35, 41, 72). Sierra Leone, indebted already as she is to foreign capitalist monopolies, will require Le 264.5 millions or 33.1 percent of the finances to translate the Plan from paper to reality. Such dependence surely opens state machinery to foreigners to provide aid for projects which they deem fit not necessarily for the Sierra Leoneans' benefit but their own ends.

Conclusion

As elsewhere in Africa, Sierra Leone's development Plans have been articulated by international experts. Input from the grassroots in plan-

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Source: African Environment, February, 1978

The regional impact of a new highway in Sierra Leone

by James A.S. BLAIR

Between 1964 and 1971, the first two phases of a major new highway running east-west across Sierra Leone were constructed, thus forming the first 80 miles of a direct link between Koidu, the heart of the nation's diamond mining activity, and Freetown, the capital. (Figure 1). By closing a previously unmotorable gap in the earlier road network, the highway radically alters traffic patterns in Sierra Leone. It is the objective of this paper to study what effects the creation of this modern highway has had on the rural areas through which it passes.

Any discussion of this new Tonkolili-Kono higway's impact will be coloured by the volume of traffic utilising the road. This will therefore be the starting point of this paper, but it is not the intention that a narrowly defined cost-benefit analysis will be undertaken on the basis of road usage. Savings in user cost, appreciable though these may be in the eyes of the individual traveller who saves a little under one hundred miles each way on a Freetown-Kono trip, are scarcely an adequate guide to the developmental impact of the road (1). Although techniques are now available to assist in the widening of the basis of cost-benefit analysis, the benefits accruing to

(1) Consideration has been given to the saving in user cost found by the major oil companies supplying petroleum to the Kono market, as petrol tankers were found to be one of the major commercial users of the road.

individuals and companies using the road are to some extend irrelevant to the highway's impact on the region through which it passes, and instead it is intended here to present logically the conclusions reached from the insights gained during both the field programmes and archival research undertaken, and also the discussions held over several years, under the broad banner of «the Kono Road Project (2). It is necessary to keep in mind throughout this discussion that the impact of the eighty-mile highway from Matotoka in Tonkolili District to Koidu in Kono District is by no means complete. Just as the loans incurred to build the road are far from fully repaid (3), so given due maintenance will the road be continuing to make an impact on the area around its line for a long time to come. Thus on-going research is endeavouring to monitor changes that are still occurring.

In the second section of this paper, attention will be turned to the development of a feeder road system, which has mostly expanded since the new highway was officially opened in 1971. While this network is no doubt itself still inadequate and incomplete, some tentative conclusions can be drawn on its initial influence on the development of the region. Clearly its creation represents an extension by area and intensity of the effect of the main highway.

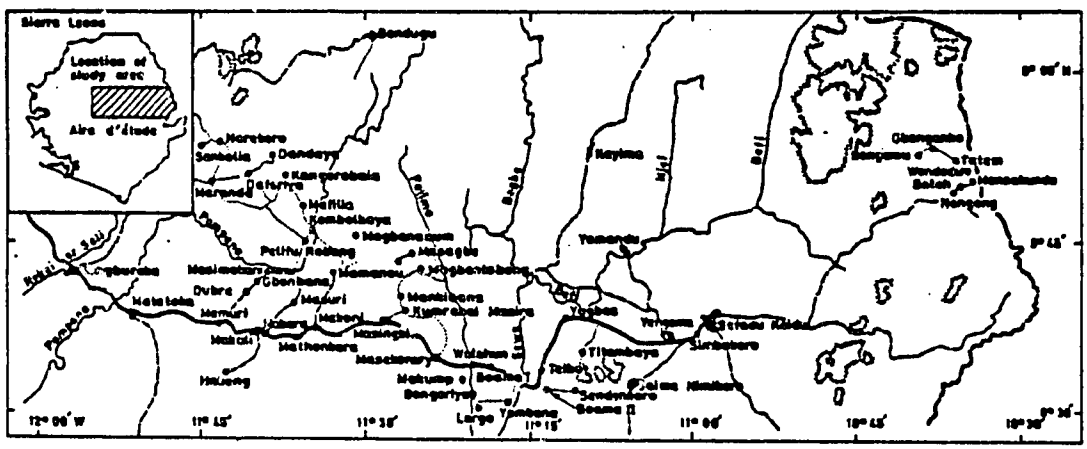
(2) The original draft of this paper was presented at a seminar on **The Implications of Development on Population** held in Freetown, Sierra Leone in July 1975 under the joint auspices of the Institute of African Studies, University of Sierra Leone and the Population Dynamics Programme, University of Ghana. The author was then Research Fellow in Economics in the Institute of African Studies, University of Sierra Leone and he is grateful for the financial support received through that Institute from the authorities of Fourah Bay College in support of «the Kono Road Project», and to Professors Eldred D. JONES and John E. PETERSON for the guidance and support they gave to the Project. This interdisciplinary team project inspired both the seminar and the paper

(3) Details of the loans received from the Government of the Federal Republic of Germany for the construction of the Tonkoli-Kono highway are as follows :

Phase	Date of Agreement	Amount DMarks	Leones 1967	Interest Rate	Grace Period	Repayment Period	% of Contract Price
I	July 1965	10 000 000	1.800.180	3%	5 years	18 years	45%
II	Dec. 1967	18.737.250	3.523.831	3%	5 years	18 years	79%

Repayment will be complete before 1990 if repayments are made on schedule. These figures were obtained with the approval of the Auditor-General from the Government Auditor who investigated the case, Mr R. BLANCHE, to whom the Kono Road Project Team are grateful for the time he took to explain the involved situation clearly.

THE KONO-TONKOLILI HIGHWAY
L'AUTOROUTE KONO-TONKOLILI


Sierra Leone
Location of study area
Aire d'étude
Bandugu
Yomandu
Yengema
Kayima
Bafi
Bofi
Sewa
Pelima
Bagbe
Kenema
Tatem
Nongowa
Yawbeko
Yengema
Sorbodu
Kissi
Tiwabeyo
Sandeniare
Boama
Bomaru
Kissi
Kissi
Kissi

Local reaction to the new Tonkolili-Kono highway is then seen through the eyes of the village headmen in communities on or near its line. A consideration of the reaction of the population at large as expressed in migratory patterns leads on from this, and the agricultural implications are drawn. Finally in the concluding section of the paper the overall impact of the road up to ten years after the initial construction was started in 1964 is assessed in the light of its contribution to the development of Eastern Tonkolili and central Kono Districts. It is the intention that the role, actual and potential, of the road can in this way be seen against a broad background of regional development, and not merely in terms of costs and «earnings».

TRAFFIC ON THE TONKOLILI-KONO HIGHWAY

Historical growth

In terms of volume of traffic alone, it is surprising that the Tonkolili-Kono highway received such priority as it did in the government's development programme. For in the mid-sixties when construction began, the one-way flow of traffic between Magburaka and Matotoka at the western end of the proposed highway was only some fifty vehicles per day (4). If allowance is made for the presumed diversion of vehicles travelling to Kono from the circuitous southern route on to the proposed new road when completed, a further 100 vehicles per day could be included as potential flow to Koidu (5), but many of the journeys included therein would in fact have been generated within Kenema and Kailahun Districts astride the existing road and would not have been diverted to the new road. So the estimated increase might more modestly have been around 100 %, bringing the likely flow to 100 vehicles eastward per day, not allowing for likely increase in road users per annum. Prior to independence it does indeed appear that only a P.W.D. Class 2 road was envisaged (6), and the September 1961 report of the consulting engineers reads as follows (Government of Sierra Leone, 1961) :

(4) Ministry of Works, A.A.D.T., Point A 5 Makoni Division (Makali Jn. - Magburka/Kumrabai Jn.). Data obtained from records in the Ministry. This figure includes vehicles that would turn southwards at Matotoka to proceed to Bo.

(5) Ministry of Works, A.A.D.T., Point B 1 Kenema Division (Bunumbu Jn. - Koidu). Data obtained from records in the Ministry.

(6) A road of this standard would be tarred and of an alignment to allow average speed of 40 m.p.h.

«The Government of Sierra Leone is considering the provision of a direct east-west road between the Tonkolili District of the Northern Province and the Kono District of the South-Eastern Province.

Field work was carried out by the consulting engineers in the latter part of the 1960-61 season. This has shown that a reasonably direct route for a road to the P.W.D. Class II standards, from Masingbe in the west to Jalama Sewafe in the east with a ferry crossing of the Sewa River, is practicable. When the traffic justified the additional expenditure, a bridge crossing of this river could be constructed, making an all weather road».

The total cost of the new section of the road was estimated at £850,000 with an additional £350,000 to improve the Makali-Masingbe road.

It is not surprising that the government of a newly independent Sierra Leone, in its desire to more rapidly promote development, envisaged a more extensive network of modern highways. It remains surprising however that the Tonkolili-Kono road emerged as such a high priority; surprising at least until the political exigencies of the period are considered. In a newly independent state, the need to maintain political continuity was in the forefront of leaders' minds, and it was possibly with the idea of attracting votes in Kono which had been previously deprived of public funds, that Prime Minister Milton Margai contacted the local district commissioners asking their assistance in making arrangements for the cutting of a trace for the proposed new road (7). Possibly in endeavouring to ameliorate relations with S.L.P.I.M. (Sierra Leone Progressive Independence Movement) parliamentarians from Kono, the Prime Minister may have been edged towards the final decision to build the long-discussed short route to Kono.

When, in July 1963, three S.L.P.I.M. members crossed the floor of the House to join the S.L.P.P. (the ruling Sierra Leone People's Party) (Cartwright, 1970, 171-3), they certainly did not have to wait long to see the commencement of the new road to Kono, a commencement on a scale and to a standard beyond what had been dreamed of in the fifties of food crises and mud-bound lorries (Van der Laan, 1965, 181-2). Nor was the political pressure for the road only expressed at the Kono end. In Tonkolili, the outspoken, revered, and long-established Alhaji Alimami Sourie, Paramount Chief of Kunike Barina Chiefdom, was exploiting most usefully his

(7) District Office, Magburaka: file: Makali-Mamensu Road and Extension beyond, R/6/3/1, Commissioner Police Freetown, to Police (Kono) and Police (Magburaka), 28 May 1960, pp.269-271.

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long standing support of the S.L.P.P. to encourage the passage of the road eastwards (8). The government certainly did not want to lose the support of this influential man.

For whatever reasons, at any rate, construction of the first class all-weather highway began in 1964 and by 1967 traffic was beginning to pass to and from Kono by the now shorter route. The Ministry of Works' bi-annual traffic counts in January and July each year give some indication of the volume of traffic utilising the road from the late sixties (Table 1). In the early years the flow was appreciably less than might have been expected as a result of diversion from the old southern route (see above), but this was probably due to the difficult passage still prevailing over the incomplete section of the road at that time. It is thus only after 1971, and the official opening of the road, that a true picture of road usage can be obtained. The results of a series of road censuses undertaken at the instigation of the present author are shown in Table 2.

Through traffic on the road

Makali, as can be seen in Figure 2, was a suitable location to ensure that all traffic using the full length of the new road was enumerated, while at the same time avoiding the inclusion of much locally generated traffic, few significant feeder roads existing in its immediate vicinity. Table 2 indicates that the total flow (two-way) of vehicles per day has remained at a fairly low level since 1972, reaching a 1973 peak of 459. Possibly because of the higher price of petrol since that time and because of less activity in the diamond areas at the eastern end of the road, there has been a subsequent downward trend of - 12.0 %, - 8.5 %, and - 30.8 % respectively for the successive years. The 1975 figure is therefore only a little above that for 1972 and by 1976 the two-way flow had declined to 75.7 % of the 1972 figure. While not indicating an identical pattern to that displayed in Table 1, the flow figures from K.R.P. surveys are of the same general order as the Ministry of Works (M.O.W.) traffic counts. As the M.O.W. figures are either for the dry season only or an average figure for the two seasons, they would be expected to be higher than the K.R.P. figures which relate to the rainy season - a drop of 10.8 % of the April flow was found in July 1972. As the

(8) Alhaji Alimani Soune had in fact been largely responsible for the extension of the original road to Makali and Masingbe around the end of the Second World War. He achieved this result by arguing with the District Commissioner that it would be impossible for the people to meet the rice quota ordered by the government, because of the difficulty of head-loading such large quantities of rice. (I am grateful to Professor J.E. PETERSON for making available to me the district archival records on this matter.)

TABLE 1

A.A.D.T. on Tonkolili-Kono Road

Two-way flow Makali-Matotoka

Year	Total	Index (1971 = 100)
1967	154	65
1968	352*	148
1969	147	62
1970	143	60
1971	238	100
1972	227+	95
1973	319	134
1974	397	167

Source : The annual daily traffic volumes are obtained from the Ministry of Works, who collect these figures over one week bi-annually in January and July. The mean of the two counts is shown.

+ This figure is from United Nations Development Programme, 1973, p. A-5, and refers to November.

* In 1968, no July survey was undertaken. This figure is perhaps grossly inflated because of the inclusion of the frequent passage of construction traffic.

TABLE 2

Makali traffic census - Two-way daily flow
(Percentage distribution in brackets)

Two-way Daily Flow

Type of vehicle	1972	1973	1974	1975	1976
Cars	73 (21.6)	75 (16.3)	118 (29.2)	76 (20.5)	56 (21.8)
Taxis	58 (17.2)	69 (15.0)	65 (16.1)	94 (25.4)	61 (23.8)
Poda-podas	113 (33.4)	162 (35.3)	122 (30.2)	88 (23.8)	66 (25.8)
Lorries	58 (17.2)	132 (28.7)	72 (17.8)	73 (19.7)	40 (15.6)
Light goods	15 (4.4)	8 (1.7.)	10 (2.5)	20 (5.4)	22 (8.6)
Buses	11 (3.2)	9 (1.9)	15 (3.7)	11 (3.0)	4 (1.6)
Unclassified	10 (2.9)	4 (0.9)	2 (0.5)	8 (2.2)	7 (2.7)
Total	338 (100)	459 (100)	404 (100)	370 (100)	256 (100)

Notes : All figures except 1976 (October) refer to July, i.e. the rainy season. Percentages are of daily two-way total flows at Makali.

TABLE 3

Traffic volume at various localities on the Tonkolili-Kono Road
(Percentage distribution in brackets)

Total Daily Flow

Vehicle Type

	Magburaka	Matotoka	Masingbe	Jaiama Sewafe	Bumpeh Jn.	Koidu
Census Point	Pampana Bridge	Makali	Sewa Bridge	Sagbe	Simbakoro	
Cars	88 (18.7)	92 (29.3)	149 (22.2)	111 (15.8)	968 (16.7)	
Taxis	64 (13.5)	50 (15.9)	301 (44.8)	327 (46.5)	4,122 (71.0)	
Poda-Podas	180 (38.2)	91 (29.0)	110 (16.4)	107 (15.2)	220 (3.8)	
Lorries	80 (17.0)	53 (16.9)	80 (11.9)	121 (17.2)	277 (4.8)	
Light Goods	49 (10.4)	21 (6.7)	20 (3.0)	23 (3.3)	61 (1.1)	
Buses	7 (1.5)	5 (1.6)	11 (1.6)	8 (1.1)	37 (0.6)	
Unclassified	3 (0.6)	2 (0.6)	1 (0.2)	7 (1.0)	123 (2.1)	
Total	471 (100)	314 (100)	672 (100)	704 (100)	5,808 (100)	
Total as percentage of peak location	8.1%	5.4%	11.6%	12.1%	100.0%	

Notes : These figures refer to surveys undertaken by K.R.P. field staff during April 1972.
The coverage was for 24 hours on normal weekdays. Percentage figures are expressed in terms of the total flow for each locality.

3d

number of vehicles newly registered in the early seventies has been at least 3,000 per annum (9), the traffic flows on the Tonkolili-Kono road have clearly been much lower than might have been expected.

Makali, with a high proportion of through traffic, is also a suitable location to consider the type of vehicule using the road. While there is some variation from year to year, the composition of the traffic flows remains broadly similar. Taking 1972 figures, and assuming that cars, taxis, «*poda-podas*», and buses are primarily passenger carrying, it can be seen that 75.4 % of all vehicles using the road carry people. This is most significant in terms of the developmental impact of the road and leads to the discussion of mobility later in this paper.

Varying utilisation of the road

For the moment it is necessary to take a wider look at the degree of utilisation of the whole road and this is done in Table 3. Basically the volume of traffic increases ever more rapidly the nearer the census point is to Koidu, and especially after the diamond heartland is entered (i.e. beyond the Nimi Hills). A quite simple pattern of traffic flows emerges, with some of the Makeni/Magburaka traffic turning off or joining the Bo road at Matotoka. Thereafter, the basic long distance traffic (plus some Masingbe-bound local vehicules) is measured at Makali and then a steadily growing number of taxi journeys boosts the figure ever higher after Masingbe. 71.0 % of the vehicles passing Simbakoro (near the eastern end of the road) are taxis, a very large proportion of them plying between Yengema and Koidu, the two main towns of central Kono. So much greater is the volume of traffic at this end of the road that the «through traffic» figure from Makali represents only 5.4 % of the Simbakoro figure : the peak hourly flow at Simbakoro (452 vehicles from 18.00 - 19.00 hours) is greater than the Makali daily flow. These figures are a reflection of the varying levels of economic activity along the road, but it is the Makali figure essentially representing the long distance traffic that remains significant, especially in view of the fact that the much-frequented Kono end of the road is busy only with taxis, carrying miners (often illicit) more frequently and more cheaply than before the road came between their places of work (often on the N.D.M.C. (National

(9) Mr WEBBER of the Central Statistics Office (C.S.O.) provided the following figures for new registrations recorded by C.S.O. assistants from police licensing office records :
1969 - 3,798. 1970 - 3,936. 1971 - 3,578. 1972 - 3,186.

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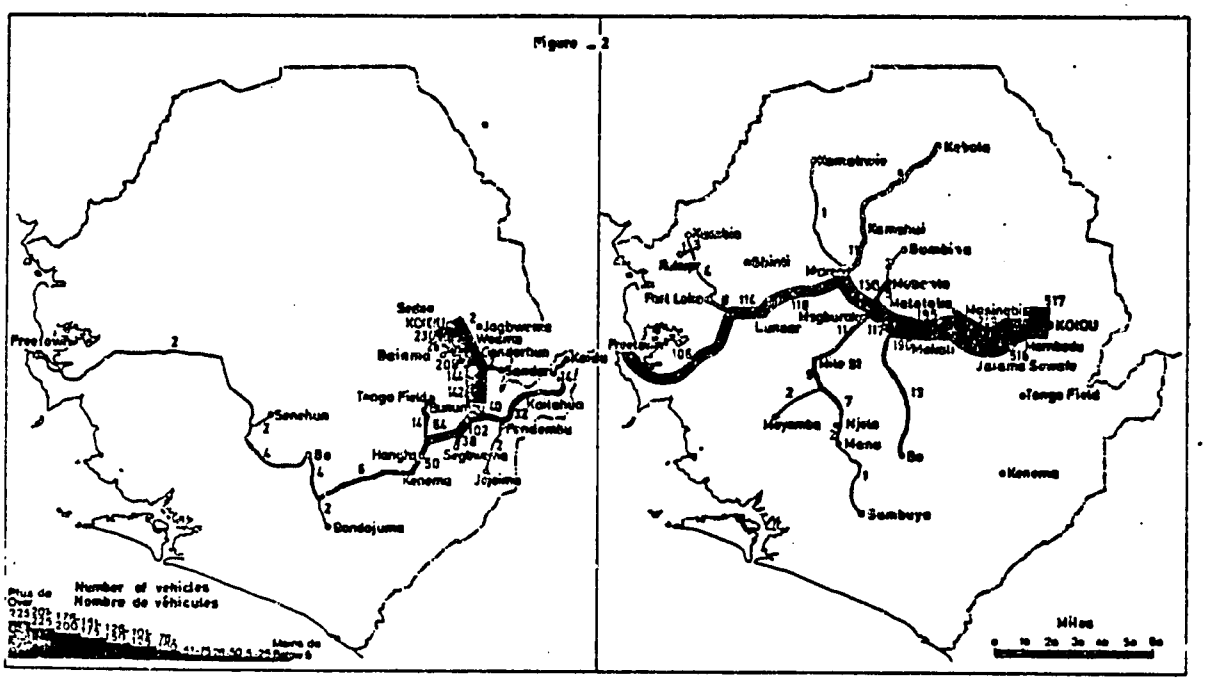
ORIGIN OF KONO BOUND TRAFFIC
ORIGINE DU TRAFIC VERS KONO



Diamond Mining Company) lease) and their places of pleasure (in and around Koidu town). The mining company (then S.L.S.T.-Sierra Leone Selection Trust) (10) long opposed the construction of a new improved highway emphasising that it would only enhance the rate of unauthorised exploitation of Sierra Leone's most valuable mineral asset and biggest foreign exchange earner - diamonds. This pattern of traffic flows on the new road justifies the company's fears.

Origin and destination of traffic on the road

Because of the attempt to control the entrance of strangers to Kono, there is a police check post at Mambodu something under twenty miles from the Koidu end of the road, but beyond Jaiama Sewafe. This proved a convenient point to conduct an origin and destination survey of vehicles using the road in June and July 1972 (11). Traffic counts were also taken at Waoma on the old road to Kono via Kenema and Bunumbu Junction (A.A.D.T. 176 inwards equalling 30.8 % of total flow of vehicles into Kono) and at Jaiama Nimikoro on the Nimi Hills road from Kenema via Panguma (A.A.D.T 30 inwards equalling 5.3 % of total flow of vehicles into Kono). The new road therefore, was in 1972, carrying 63.9 % of traffic entering central Kono. The percentage distribution of the vehicles by origin is shown in Table 4 (Figure 2), almost half of the vehicles passing the Mambodu barrier in fact starting their journeys within Kono itself mostly at Jaiama Sewafe. Masingbe generated a further 9.4 % of the vehicles and Magburaka/Makeni 12.0 %, implying that 71.9 % of vehicles passing Mambodu eastbound travelled less than 100 miles, and started their journeys at places along the new road or in the

(10) Diamond mining began in Sierra Leone in the mid-late thirties when Sierra-Leone Selection Trust, a sister company to Consolidated African Selection Trust operating in Ghana, started operations in Kono District. In the mid-fifties, the company's nation wide mining rights were renegotiated to include only two leases, one in Kono District and one in Kenema District. In 1970, the Government of Sierra Léone negotiated the purchase of 51 % of the shares of S.L.S.T. to form N.D.M.C., and hence increase indigenous involvement in, and control of, this key industry.

(11) Grateful acknowledgement of the cooperation given by the Sierra Leone Police Force is expressed. However, to avoid causing any delay to traffic movement, the field assistants conducting the survey interviewed only every fifth vehicle's driver. For reasons of economy, the survey covered daylight hours only (9.00a.m. - 6.00p.m.) and was continued for one month (mid-June to mid-July 1972). In all, 1,126 interviews were conducted at Mambodu. Information recorded included make and type of vehicule, number of passengers, origin of journey, destination, frequency of journey, when last made journey, purpose of journey, loads carried.

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TABLE 4

Origin of vehicles travelling to Kono via Mambodu
(Percentage Distribution)

Origin	Percentage	Cumulative Percentage
Jaiama Sewafe	46.6	
Other Kono	3.1	
Total Kono		**49.7**
Masingbe	9.4	
Makali	0.8	
Total on New Road		**59.9**
Magburaka	5.4	
Makeni	6.6	
Total within 100 miles		**71.9**
Mabonto/Bumbuna	0.8	
Kabala	1.5	
Bombali Dt.	0.7	
Mile 91	0.3	
Kambia Dt.	0.7	
Lunsar	0.7	
Port Loko Dt. (Other)	0.7	
Bo (Town and Dt.)	2.2	
Other Southern Province	1.5	
Freetown	18.5	
Total		**100.0**

Source : Survey undertaken by K.R.P. research assistants at Mambodu Police Post on the new highway from mid-June to mid-July 1972.

towns just beyond its western extremity (and later connected by its extension). Freetown was the only other significant origin of journeys - 18.5 % of all vehicles enumerated emanating from there - and this figure represents almost two-thirds of vehicle flows generated beyond the area of the road itself, and underlines the administrative, commercial, and economic significance of the capital throughout the country.

Classified by function, vehicles passing Mambodu en route for Kono were found, as at Makali, principally to be carrying people - 66.2 % transporting passengers, 12.9 % being used for personal travel, 12.6 % transporting goods, 6.1 % transporting petroleum, and 2.2 % transporting wood. The sale of wood along the road has been an oft-noted effect of the new line of communication, and the price of fire wood fell markedly in Koidu as a consequence. The obvious longer term effect has been that the area has a much more open and treeless appearance than a few years ago. These figures overall, however, emphasise the non-economic nature of most journeys made on the road.

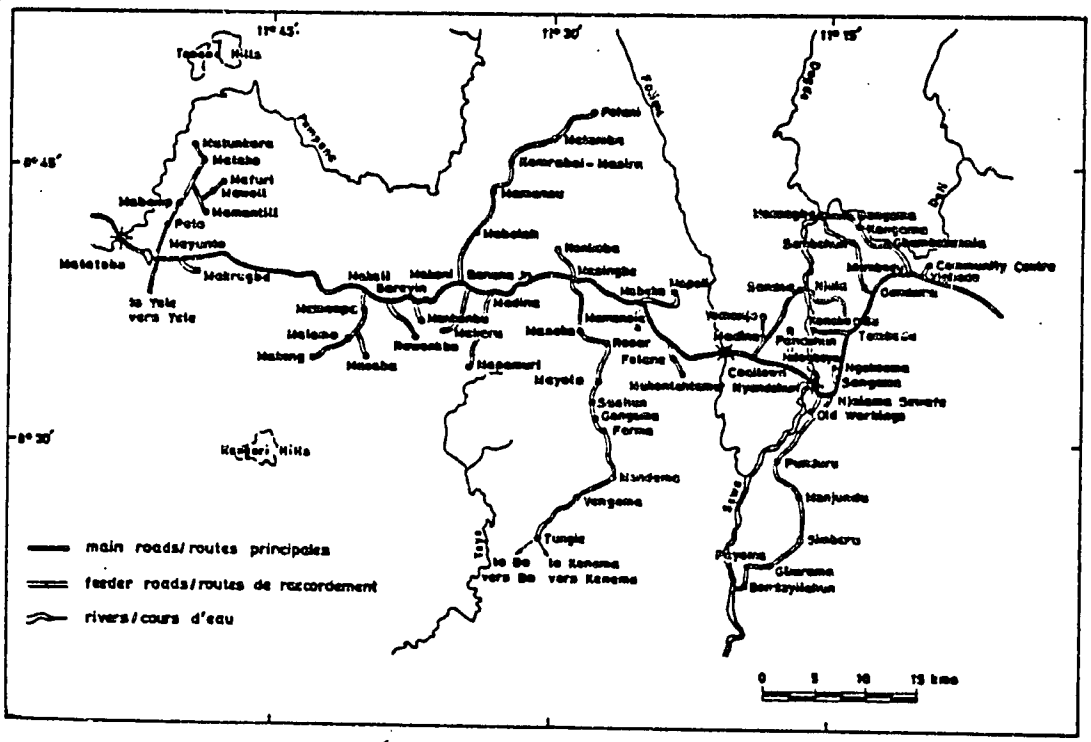
As a result of the origin and destination surveys it was possible to obtain a figure for the average number of passengers (other than the driver) carried by all vehicles. This figure (5.1 persons) means that the daily flow of people eastwards past Sagbe at the gap in the Nimi Hills where the road enters central Kono, is 1,856, of which approximately 925 begin their journeys outside Kono. These figures serve to underline that a study of the effect of the new Kono road is in fact a study of people on the move.

FEEDER ROAD DEVELOPMENT

At the time of the construction of the Tonkolili-Kono road, only the section of the road in central Kono (approximately ten miles from Bumpeh Junction to Koidu) was well served by feeder roads. These had been developed during the decades of intensive diamond mining activity and their standard tends to vary with the level of mining activity. This area will not be included in the discussion that follows.

In 1972, when the K.R.P. team first examined the feeder road network along the seventy miles of road from Matotoka to Bumpeh Junction, there was no through route intersecting the highway between these points. At Matotoka, the long established P.W.D. (Public Works Department) road to Yele and Bo ran south, and at Bumpeh Junction a similar road also ran south to Jaiama Nimikoro and Kenema. The longest road between these points in 1972 was the Makoni-Mamansu road which ran approximately seven miles to the north of the highway starting halfway between Makali and Masingbe (Figure 3). This road had been built prior to the construction of the new road. Indeed it had once been considered that the new highway would pass much to the north of its present line, passing through Mamansu and Sumbaria. Halfway between Masingbe and Jaiama Sewafe, a short road (around 1-1/2 miles) had been built in 1968 to link the

DISTRIBUTION OF FEEDER ROADS
RESEAU DE RACCORDEMENT



village of Fotanetama to the main line, and the headman there claimed that it had brought two shops to the town. In Kono, a road (approximately four miles in length) had just been built for mining purposes to Gbambakunaia from near the Mambodu police barrier, and another from Gondama on the main road led through several small villages to the mining boom town of Massagbendu. These few roads apart, there had been little development of feeder roads up to 1972. This no doubt contributed to the low density of traffic on the main highway.

In 1974, a rainy season survey was undertaken to map the distribution of all feeder roads leading off the main highway between Matotoka and Bumpeh Junction (12). A very changed position was found as displayed in Figure 3. In all, over 142 miles of feeder road had been developed, implying a ratio of two miles of feeder road per mile of tarred highway.

88 villages were thus linked to the main line of communications, with a 1963 population of approximately 17,000 persons. The standard of the roads was almost ubiquitously poor - narrow with little room to pass, obstacles such as rocks and even roots rarely removed, bridges mostly of palm tree construction and often in bad repair, excessively steep gradients, and swampy sections liable to flooding. But despite the fact that the survey took place in the deep rains, very rarely did it prove impossible to reach the road-head by landrover. In this sense the roads were functioning as required, and several had established on them regular or semi-regular public transport flows (usually a Toyota *«poda-poda»* or a landrover providing the service).

The functions and method of construction of the roads varied to some extent, especially between Kono and Tonkolili Districts. In Kono, construction was usually associated with mining, especially in the provision of access roads to the rivers Sewa and Bafi. Gangs of miners, therefore, were often responsible for their construction, or on some occasions a «mining magnate» provided earth-moving equipment to cut and grade a more ade-

(12) The survey of feeder roads was undertaken by following every entrance on both sides of the road between Matotoka and Bumpeh Junction in a landrover, and mapping the route on 1: 50,00 map sheets. Condition was recorded by visual observation, and date and method of construction were obtained from the headmen or elders of villages on the feeder roads. On some occasions the local Paramount Chief would accompagny the research team.

quate road to his mining plot. The most prominent entrepreneur of this ilk is Alhaji Sesay, who has a large compound at Coaltown on the new road from which he has built an extensive road system to reach various mining sites along the west bank of the river Sewa. Some such mining villages have grown to contain well over a hundred corrugated-iron-roofed houses, although previously they were not even shown on the 1 : 50,000 map sheet (e.g. Sandea on the river Sewa).Road construction associated with mining is therefore responsible for swift and dramatic changes in population distribution typical of a boom economy associated with valuable mineral exploitation. Where the mining occurs in an area of previously thick forest (as it often does along the Sewa), the exploitation of the forest is a side effect of the major presence, many farmers farming part time in previously undeveloped areas, and so widening the impact of the road on vegetation to affect a greater area.

In Tonkolili District, road construction has tended to proceed in a more orderly way under the guidance and through the stimulation of the Paramount Chiefs of Tane, Kunike Barina, and Kunike Chiefdoms, all of whom have actively encouraged their village headmen to engage communal effort in the construction and maintenance of road links. The immediate purpose is agricultural stimulation, usually through improving access to markets or sometimes as in Kunike Barina to allow the passage of a tractor to develop swamp cultivation. The time-consuming and laborious task of head loading can also be avoided. Mining has been an insignificant stimulus to road construction in Tonkolili District although the area is undeniably rich in minerals. In the case of the 6-1/2 mile Makali-Makong road, the construction of the road was followed by the reactivation of gold mining in the latter town, but this is possibly more associated with the, albeit temporary, rise in the market price of gold at that time than with the arrival of the road. In the 1930s Makong was a mining boom town, where the London-based Mining Company of Marc had a labour force of 700 (Fowler-Lunn, 1938, 135-8), but over the years had declined to 24 occupied houses, so that the local paramount chief had to encourage labour to go there to reactivate mining.

The role the paramount chief as the agent and organiser of development at the local level can clearly be seen in the matter of feeder road expansion. In the case of the feeder roads, perhaps because of the close affinity of the chief and his people who want to know how their efforts at constructing a road will benefit them, there has tended to be associated development

such as the introduction of tractor ploughing, or even just of swamp seed rice and possibly of fertiliser. In this way, the feeder road development programme has been superior to the development of the national highway network and the outcome of its arrival may therefore vary too. In terms of costs also, feeder roads have made a negligible drain on national resources, in fact usally being constructed by what has historically been known as «communal labour», and in modern terminology is called «self-help». The quality of the roads may not be high, but it seems adequate, for the moment, to allow the roads to serve their function.

In one case, feeder roads have now linked up with the network of feeder roads in Mende country to the south, and eventually those join up with the Bo-Kenema highway. These routes run from Masingbe via Mayola, Saahun, and Mondema to Tungie, which has long had roads via Konta to Kenema, and to Bo. The Ministry of Works have recently been assisting the local chiefs by providing cement for bridges and culverts, and no doubt this is indicative of the future trend when a much denser network of properly maintained feeder roads will link up the rural communities of Sierra Leone.

LOCAL REACTION TO THE ROAD

It is manifestly true that the consequences of the provision of a major infrastructural development such as the new Tonkolili-Kono highway will depend to a considerable extent on the reaction of the inhabitants in the area through which it passes and on their degree of responsiveness to the new opportunities that will arise. In this paper, account is not taken of the urban reaction to the new road (centred in the district headquarter towns of Magburaka and Koidu-Sefadu), as this is considered more fully elsewhere (Blair, 1973). It is thus the opinion of the village headmen and of the rural communities that is here being considered. However, it seems appropriate to focus attention there as the research area is predominantly rural and agricultural. In 1963, Kunike, Kunike Barina, and Tane, the three Tonkolili chiefdoms along the road, had respectively 22.8%, 15.3%, and 10.8% of their population living in localities of more than 500 persons, although the proportion rose to 56.9% in Nimiyema and 59.6% in Nimikoro at the Kono end of the road (Government of Sierra Leone, 1965, Vol. I, Table 7). The proportion of the working population described in the 1963 census as farmers, fishermen, or related workers was as follows : Tonkolili District - 96.4 % (the highest proportion by a small margin of any district in the country); Kono District - 89.9 % (no doubt disguising a sizeable number of part-time or even full time diamond diggers) (Government of Sierra Leone, 1965, Vol. III, Table 7).

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The K.R.P. field research teams conducted in 1972 censuses of 52 villages on the line of the new road or within six miles of it. In each of these villages the headman was asked if he found any disadvantage arising from the coming of the new road. In 37 cases, no disadvantage was noted and in one more case the only complaint was that the road did not pass through the village concerned. In seven villages, grievance was expressed over failure to pay compensation due to the destruction of plantations but it was not investigated whether this was a real or imagined grievance. Certainly it arose more from the process of construction than from the existence of the road *per se*. In most other cases, the headmen, through age or lack of interest perhaps, stated that they were unable to tell whether or not any disadvantage had arisen as a result of the existence of the new road, although a few mentioned the prevalence of thieving, arising from the freedom of access to their villages. More positively in response to a question on what advantage they felt the road had brought their village, 31 headmen spoke primarily in terms of quicker/easier/cheaper transport, while six more noted the greater accessibility to markets in which to sell their produce. Eight felt that the greatest advantage was that more traders and visitors generally came to the village, while only two headmen welcomed the road because it had caused more people to come and settle in their communities. Only five headmen saw no advantage at all arising from the existence of the road, but their villages were in fact those further from the line of the road. The fact that the road was welcome to the leaders of the rural communities in its vicinity, however, is scarcely surprising, nor does it mean that a very great response in terms of development will follow. For the villagers interviewed seemed permissive rather than positive in their attitude to development, many repeatedly expressing expectations in terms of what government should do next, rather than what they themselves intended to do. It seems that the leadership role of the paramount chief here can be of crucial significance.

In a subsequent section of the paper, attention will be focussed on the stimulus to emigration provided by the cheaper and swifter transportation that the road has allowed. However, it is also significant to note here what headmen felt had been the effect of the construction of the road in bringing more strangers to their towns. Their feelings on this point are displayed in Table 5. In both Tonkolili and Kono Districts, the trend was similar - overall exactly half of the headmen opining that there were no more strangers

present in their village because of the coming of road road. Approximately half of the remaining headmen (23.1 % of the total) felt that more traders visited their village, and the other most significant reason for new arrivals was the utilisation of resources for economic purposes (farming in Tonkolili and mostly diamond mining in Kono).

As agriculture is the primary source of employment in the area, headmen were asked how they felt agriculture had been affected by the coming of the road. The largest single group of headmen (44.2 %) were of the opinion that agriculture continued unaffected (Table 6), while 26.8 % thought that it had been stimulated either in the form of expansion or of better access to markets. In contrast a group of headmen (25.0% in all) felt that the extent of farming had declined, or that the production was being affected by labour

TABLE 5

Visits by Strangers to Villages on or near the Tonkolili-Kono Road
(Headmen's Opinions)

Visits	Kono District Frequency	Tonkolili District Frequency	Total Frequency	%
No more strangers	10	16	26	50.0
More strangers as visitors	2	1	3	5.8
More strangers as traders	4	8	12	23.1
More strangers as thieves	1	0	1	1.9
More strangers for diamonds	5	0	5	9.6
More strangers to farm	1	4	5	9.6
Total Villages	23	29	52	100.0

TABLE 6

Effect on Farming in villages on or near the Tonkolili-Kono Road
(Headmen's Opinions)

Effect on Farming	Kono District Frequency	Tonkolili District Frequency	Total Frequency	%
Farms increased in numbers or size	4	8	12	23.1
Farms decreased in number or size	1	4	5	9.6
Not affected	11	12	23	44.2
Better access to markets	1	1	2	3.8
Farm labour shortage	4	4	8	15.4
Unknown	2	0	2	3.8
Total Villages	23	29	52	100.0

shortage. The impact of the road on agriculture is therefore, at least in the voiced opinion of the interviewed headmen, not clear. However, opinion on the effect of the road on prices at which agricultural produce can be sold is more definite - 31 of 52 opining that prices had increased (21 of 29 in Tonkolili District which had previously been more remote from the lucrative diamond area markets). In 1972, prices of rice (the main agricultural commodity) had not really started on their dramatic upward trend in Sierra Leone, and the headmen may therefore well be correct in attributing the rise in price to the ease of access to more lucrative markets. As low market prices have long been held to be a major depressant in Sierra Leone on rice production in particular, and on farm production generally, it can be argued that better access to competitive markets has encouraged agriculture, especially in the previously more isolated areas.

However, as far as incipient initiative and enterprise is concerned in the dominant agricultural sector of the area, prospects do not seem markedly bright without external guidance. When asked what future developments they thought might be envisaged in agriculture now that the road was there, 20 headmen said «*none*», and 13 more did not know of any; six stated that

there would be future development but had no specific ideas on what its nature would be; four mentioned the possibility of obtaining fertiliser and one was in favour of electrification of his farm (details not specified !) The remainder spoke only vaguely of expansion or more sale. It seemed overall, that there was need for stimulation of thought on the potential, especially the agricultural potential, in the future.

In concluding this section on village response, it must be noted that often the headman of the village is not the leader of change. Indeed, if as in many cases he is elderly and confused by the 1970s and the world around him, be may be actively resistant to change. A better guide of responsiveness can perhaps be obtained by a scrutiny of the population at large, which to some extent indicates individual response. It must too be emphasised again that the natural growth poles of the research area - Magburaka and Koidu - are excluded from the present discussion, although it can be noted that the conclusion of a survey of non-agricultural enterprises in central Kono were that the new road had stimulated little response in terms of new investment or creation new enterprises. (Blair, 1973) :

«The survey of entrepreneurs in Kono in fact paid special attention to the response of entrepreneurs there to the new opportunities created by the coming of the new Tonkolili-Kono road... The degree of response is at least partially disappointing. For less than half (47 %) of the entrepreneurs surveyed in fact found the road beneficial... In only one case had the business opened as a result... On the other hand 15% of the entrepreuneurs had felt no effect on their business, and 40 %. found the effect of the road detrimental...».

MOBILITY AS A RESPONSE TO DEVELOPMENT

In 1972, K.R.P. research teams undertook a census of 77 villages in Tonkolili and Kono Districts. 52 of the villages included are those on or near the road, referred to above, and the remainder are intended to represent *«control»* areas for comparative purposes, i.e. areas that have not been subjected to the impact of the arrival of a nearby highway. The 32 village communities in Kono District are more complicated in their response to the highway because of their greater pre-road exposure to the economic activity and agricultural markets of the diamond areas, and because of the response in terms of emigration or immigration to diamond mining both pre and post the new road. For this reason, the present analysis of the response to the new highway in terms of mobility of population is confined to Tonkolili District.

TABLE 7

Change in Population 1963-1972 for Selected Tonkolili Communities
Percentage Distribution

Area	Change of Population as % of 1963 Population	Change of Males as % of 1963 Males	Change of Females as % of 1963 Females
Tonkolili Control	— 16.5	— 15.5	— 17.5
Tonkolili Road	— 20.6	— 21.0	— 20.1
Villages on or less than 1 mile from the road	+ 17.6	+ 12.0	+ 23.8
Villages more than 1 mile from the road	— 25.6	— 24.5	— 26.7

Sources : The data for 1963 are derived from a listing of community populations provided by the Central Statistics Office and based on 1963 Census data. The data for 1972 were obtained by K.R.P. survey teams undertaking a census of these communities.

Looking first at the change of total population between 1963 and 1972, we find in Table 7 overall decline but the decline is greater in the Road Area than in the Control Area - 20.6 % - 16.5 % respectively. The trend is more marked in the case of the percentage decline in the male population - 21.0% in the case of the Road Area and - 15.5% in the case of the Control Area. These figures appear to indicate that the areas of proximity to the highway development have been subjected to greater population drainage than those more isolated from its impact, as medical facilities which would affect the rate of decline by reducing death rates are more extensive nearer the highway. The pattern of mobility can be more closely followed when, within the Road Area, distinction is made between the group of villages on or less than one mile from the road, and those further away from it. The villages on the road grew in population by 17.6 %, while those in its hinterland declined in total population even more dramatically - by - 25.6% overall. In the case of the villages on the road, the percentage increase was much higher for females than for males - 23.8% against 12.0 %. This phenomenon could possibly be explained by the tendency of males to continue up the steps of a migration ladder to ever larger urban centres, but it would be beyond the scope of this paper to prove this point, which has been discussed elsewhere (Mills, 1973).

The age-sex distribution of the surveyed villages (Table 8) conforms with extensive emigration of young adults of both sexes, but especially of males. From a marked excess of males in the 5-15 age cohort, the sex ratio drops in the two succeeding cohorts respectively to 59.5 and 71.2 males per 100 females. Young adult female emigration is itself evidenced by the drop in the number of females between the second (5-15) and third (15-25) cohorts from 986 to 593, or by 39.9 % of the former. It appears therefore that an already established pratice of rural exodus amongst young adults for reasons discussed elsewhere (Mills, 1973; Blair, 1977) is accentuated by the presence of a modern highway which removes many of the obstacles to the actual act of migration, bringing cheaper and faster means of transport, more recent and accurate information of urban opportunities, more frequent demonstration of the relative affluence of passing travellers, and the possibility of a prompt return if the urban experiment fails.

Against a backgroung of little stimulation of new activities in the rural areas, as discussed, it is necessary to consider the impact of this emigration on the agricultural communities it affects. The cultivation of upland rice by traditional bush fallow methods remains the primary aim of most farmers in Tonkolili District (Blair, 1977). Gradually, cultivation of inland valley swamps is spreading, encouraged by the improvement in communica-

TABLE 8

Age-Sex Distribution for Selected Communities in Tonkolili District 1972

Age Cohort	Males	Females	Total	Males/100 Females
0 < 5 years	620	624	1,244	99.4
5 < 15 years	1,249	986	2,235	126.7
15 < 25 years	353	593	946	59.5
25 < 35 years	445	625	1,070	71.2
35 < 45 years	406	393	799	103.3
45 < 55 years	299	255	554	117.3
55 < 65 years	179	151	330	118.5
65 and over	167	121	288	138.0
Total	3,718	3,748	7,466	99.2

Source: Census of 45 villages undertaken in July/August 1972 by Kono Road Project research assistants.

tions, by greater availability of seed rice, and by government extension services. The degree to which tractor ploughing is associated with this development varies especially with the extent of the individual swamps, only the larger ones being suitable for mechanised cultivation. Swamp rice production is in any case more labour intensive than upland cultivation, transplanting being an entirely new task in the farming cycle. Overall labour inputs to swamp cultivation tend to be 17.1 % higher than those required for a similar acreage of upland rice farming, without even taking into account the considerable labour requirement of initial swamp clearance (German Development Institute, 1973, 78-80). Additionally, an oft-expressed advantage of the shift to swamp cultivation, other than the near doubling of yields on average, is the greater soil stability that can prevail on the hillsides through the introduction of tree and other plantation crops including fruits which have high labour demands, not least for harvesting

Ironically, it appears that the agricultural opportunities that improved communications bring, notably through allowing improvement in techniques through partial mechanisation and through enhancing the motivation of the individual farmer by offering him better prices as a result of easier access to a wider range of markets, may be severely curtailed by the

limitations in labour supply. The apparently attractive urban opportunities tempt agricultural labour away from the rural areas to seek better social and economic prospects, just at the very time innovation and change on the agricultural scene can improve the economic prospects of village life, while swift transport means that urban social activities can be enjoyed on a visiting or weekend basis. The opportunities that new lines of communication may bring the agricultural sector will be largely missed, unless official action can intervene to stimulate interest and confidence in rural prospects, in anticipation of, and simultaneously with, the development of communications. The gap between the rural anticipation of urban opportunities and the reality of widespread unemployment in the towns endorses the necessity for positive preventive action.

CONCLUSIONS

The range of evidence discussed in this paper has tended to suggest a pattern in which the new Kono-Tonkolili highway has manifested little positive developmental impact, at least on the rural areas through which it passes. Even in terms of population mobility, evidenced as high in various ways, the road appears to have accelerated the tendency of the young to emigrate. Certainly communities near, but not on, the highway display the most rapid decline in population between 1963 and 1972 (the period spanning the years from the decision to build to the formal opening of the road), but at the same time absence of part of the economically active age group runs widespread throughout the research area, or at least the Temne (Tonkolili) part of it. While the high proportion of population engaged in agriculture in Sierra Leone will obviously decline to allow productivity in this sector to rise and to achieve a better balance in the economy, the rate of decline has to be carefully controlled to avoid mass urban unemployment. It seems that the response to the road has not for the most part been one of burgeoning rural enterprise generating local non-farm employment, but rather one of utilisation of better communications to travel more frequently to larger communities with a wider range of economic opportunities and greater social, educational, and medical amenities. This movement may be very temporary (e.g. a trading visit) or very permanent (e.g. a lifetime's employment). It would be false however to leave the impression that nothing has happened in the wake of the road. In the chiefdom towns along the road new shops and petrol stations, new secondary schools (e.g. at Masingbe and Makali), new agricultural efforts (e.g. the Chinese-sponsored development of a swamp seed rice farm at Makali) all contribute to a gradual and positive pattern of development, and to the improvement of the quality of rural life.

The question that remains poised over the new Tonkolili-Kono highway and other similar projects in the developing world, however must always be, could the nation afford this investment in terms of the contribution it has made to development ? It has already been shown that the road does not earn revenue for government, and that it is to the individual road user that the benefit goes in terms of savings in user cost. It appears that the effect of the road in generating economic activity, at least in the rural areas through which it passes, is small. Yet the road has cost in the end in the neighbourhood of Le 160,000 per mile, total costs being Le11.9 million. Estimates of the cost of this road were nowhere so high when the decision to build the road was made by the S.L.P.P. government of Sir Milton Margai (13). Indeed they were still much more modest than today's costs when Albert Margai's government signed the first loan agreement for DM 10 millions in July 1965 with the West German Government. The National Reformation Council's signature to the second loan agreement perhaps escalated the final costs somewhat by oversighting the clause that repayment would be in deutschmarks at the rate of exchange current at the time of repayment (14). With the leone tied to an ailing pound, and the deutschmark's tendency to repeated revaluations, the lot of the present All People's Congress (A.P.C.) Government has been to open the road, and begin to pay the bill - renegotiating the terms of aid where possible, and rescheduling payments when necessary. That the infrastructure of a developing nation should be developed is obvious; that some benefits derive from its development would be expected; but the rate of development should be geared to the capacity of the nation to utilise the infrastructure fruitfully as an agent of general economic development. It would appear, at least from the limited perspective of this paper, that the new Tonkolili Kono highway is not «earning its keep». There is need therefore, for consideration of the possible justification of tolls, and certainly for a search for economic opportunities in the hinterland of the highway which can be exploited to allow the new road to make its contribution to national development. In general it seems that carefully planned and fully integrated regional development planning could have ensured both that the local impact of the new highway was controlled, and also that the road be put to greater economic use; only in this way could such a large investment justify itself.

(13) The estimate for Phase I and II to class 1 standards was 8.5 million leones, against 5.0 million leones for class 2. All estimates and final cost figures were supplied from the office of the Auditor-General.

(14) Mr BLANCHE provided figures relating to all four phases of the road from Lunsar to Kodu as follows. Total loans received were DM. 55,737,250. In leones, this was Le 11,914,720. Repayment (including interest etc.) at the same rate of exchange would equal Le 15,629,839, but by July 1973, one year after repayment had started, the leone equivalent of the same number of DM. was Le 24,113,713, and today the situation would have deteriorated further. The increment in total costs due to exchange rate fluctuations is thus seen to be at least Le 8.48 million.

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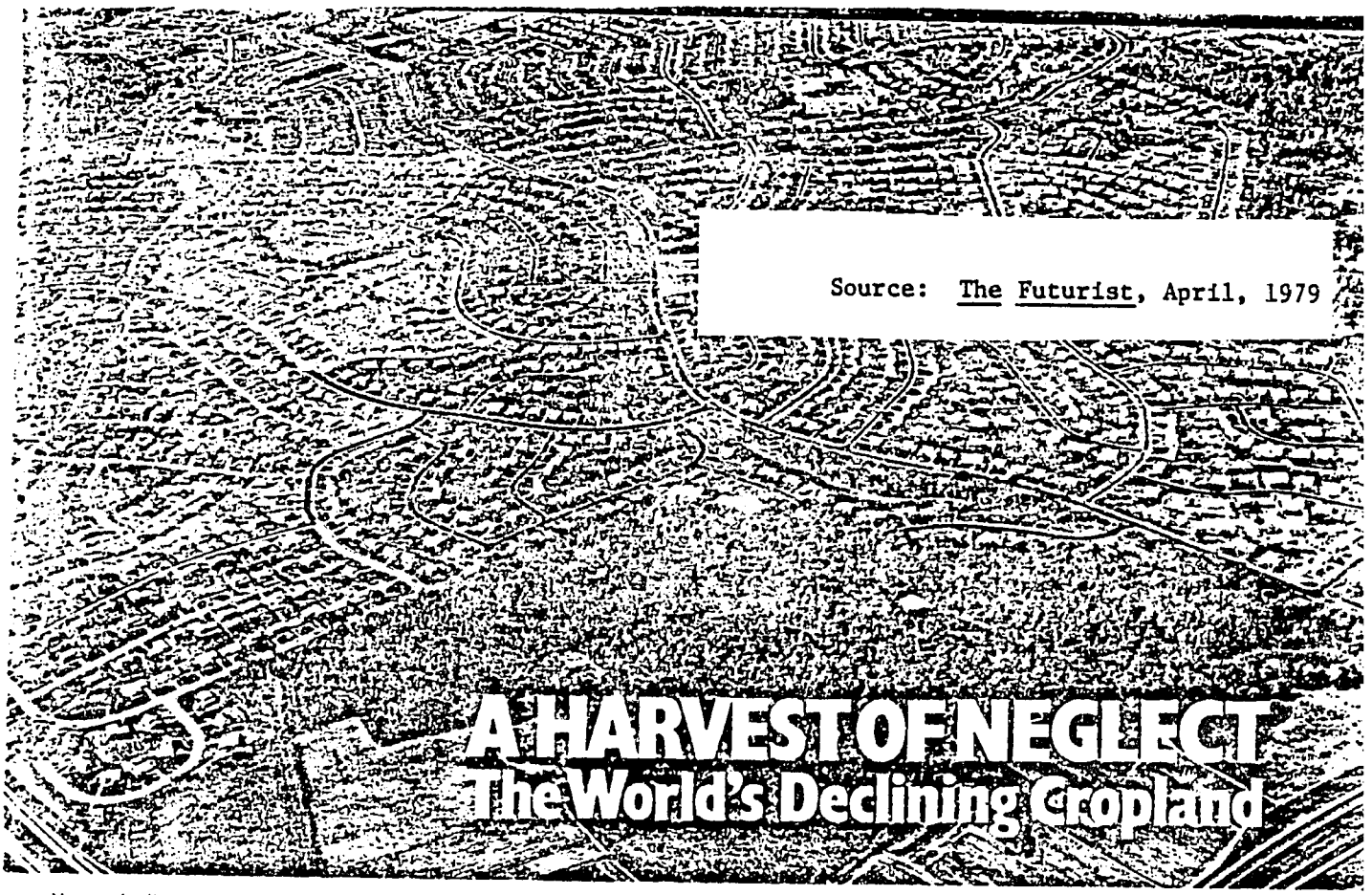
AGRICULTURAL ASPECTS
OF LAND USE PLANNING

1. "A Harvest of Neglect- The World's Declining Cropland"
2. "Rural Land Use Planning"
3. "Food for Fuel- Competing Uses for Cropland"
4. "The Conversion of Tropical Forests"



Source: The Futurist, April, 1979

A HARVEST OF NEGLECT
The World's Declining Cropland

Non-agricultural demands such as urban expansion and growing transportation systems pose serious threats to the world's cropland base. This housing development is in Prince George's County, Maryland.
Photo: USDA—Soil Conservation Service

by Lester R. Brown

Between 1950 and 1975, the entire world enjoyed an agricultural revolution unparalleled in history. But unless protective measures are soon taken on an international scale, the last quarter of this century may see invaluable portions of the world's productive cropland swallowed up by expanding deserts, urban sprawl, and the insatiable demands of population growth.

Ever since the beginning of agriculture, the area and fertility of cropland has determined the availability of food. When land is scarce, people often go hungry. When soils are depleted and crops are poorly nourished, people are often undernourished as well.

Pressures on the world's cropland have escalated since mid-century as our numbers have increased, raising doubts about long-term food security. In 1950 there were 2.5 billion people in the world. In 1975 there were 4.0 billion. By the end of the century, there will be 6.3 billion of us if current projections materialize.

Growing populations demand more land not only for food production but for other purposes as well. Even as the demand for cropland is expanding at a record rate, more and more cropland is being converted to nonagricultural uses. In addition, the soaring world demand for food since mid-century has led to excessive pressures on the more vulnerable soils. This in turn has led to soil degradation and cropland abandonment.

Cropland deterioration and loss are not new problems. The Tigris-Euphrates Valley, once described as the Fertile Crescent, may have formerly supported more people than it does today. The food-deficit lands of North Africa were once the granary of the Roman Empire. What is new is the scale of cropland loss and soil deterioration, a problem that now affects all countries, rich and poor alike. Natural soil fertility is now declining on an estimated one-fifth of the world's cropland.

Direct evidence of the mounting pressures on the global cropland

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"Natural soil fertility is now declining on an estimated one-fifth of the world's cropland."

base is also seen in accelerating soil erosion, the spread of deserts, and the loss of cropland to nonfarm uses. In the Central Sudan and Northwest India, sand dunes now occupy the land where villages once stood. In the midwestern United States, shopping centers occupy land that only a few years ago was planted to corn. Factories are being built in southern China on land that for generations yielded two rice harvests each year.

Indirectly, excessive pressures are reflected in falling crop yields, growing food deficits, and a greater instability in the world food economy. Crop failures are more frequent, as cultivation is extended onto land with less reliable rainfall. During the 1970s, prices of wheat, rice, and soybeans have doubled in times of scarcity. After a quarter-century absence, famine returned in the 1970s, claiming hundreds of thousands of lives in Bangladesh, Ethiopia, and the Sahelian zone of Africa. The food shortages that led to these deaths were initially blamed on poor weather, but weather was often the triggering event that brought into focus a more fundamental problem—the growing pressure on local land resources.

Conversion to Nonagricultural Uses

As noted earlier, the increase in world population and economic activity means that land is needed for much more than just the production of food. The principal non-agricultural needs are urbanization, energy production, and transportation. Each of these sectors is now claiming cropland in virtually every country.

Wherever national data are available, they usually show the growth of cities to be a leading source of cropland loss. Within the United States, cities are consuming cropland at a record rate. Land-use surveys by the U.S. Department of Agriculture in 1967 and 1975 indicated that some 2.51 million hectares of prime cropland "were converted to urban and build-up uses" during the eight-year span. A study of urban encroachment on agricultural land in Europe (grasslands as well as croplands) from 1960 to 1970 found that West Germany was losing 0.25% of its agricultural land yearly, or 1% every four years. For France and the United Kingdom, the comparable figure was 0.18% per year, or nearly 2% for the decade.

While data are available on the loss of agricultural land to cities in the industrial countries, there is little information on the Third World, where the most rapid urbanization is occurring. Scores of cities in developing countries, such as Lima, Ankara, and Manila, are growing by 5 to 8% yearly. Inevitably, some of this growth comes at the expense of cropland.

Further east, China, the world's most populous country, is also losing cropland to cities and industry. USDA China specialist Alva Erisman reports that "water control projects, urban growth, and the appropriation of agricultural land for roads, railroads, airfields, industrial plants, and military uses have removed good farmland from cultivation." Dwight Perkins, Chinese scholar at Harvard, makes the same point, noting that the 10% growth in modern industry, with factories commonly sited on the edges of cities, has undoubtedly used up cropland. He believes Chinese planners are aware of this continuing loss of cropland, but that "there is no way around the fact that good farm land (flat, located near transport, et cetera) often makes an excellent factory site."

Rivaling the urban sector as a claimant on cropland is the fast-growing global energy sector. Hydroelectric dams often inundate vast stretches of rich bottomland; electric generating plants can cover hundreds of hectares. More often than not, oil refineries and storage tanks are built on prime farmland along rivers and coastal plains. Strip-mining of coal and the diversion of irrigation water for coal gasification both tend to reduce the cultivated area.

In the United States, the Senate's Committee on Interior and Insular Affairs analyzed President Ford's 1975 State of the Union Address in which he asked for "200 major nuclear power plants, 250 major new coal mines, 150 major coal-fired power plants, 30 major new refineries, 20 major new synthetic fuel plants, and the drilling of many thousands of new oil wells" in the next 10 years. The Federal Energy Administration estimated that the program would disturb land on some 18 million hectares. The Senate Committee noted that "this amounts to a tripling of the amount of land currently devoted to energy thus far."

All transport systems require land, but some systems use much more than others. Automobile-centered transport systems are voracious consumers of land. Millions of hectares are required just to park the nation's 143 million licensed motor vehicles. But even this is rather small compared with the land covered by streets, highways, filling stations, and other service facilities. Moreover, the automobile has encouraged other inefficient uses of land, such as urban sprawl.

The amount of cropland that will be paved over, built on, strip-mined, or flooded by a dam by the end of this century is unknown. However, if world population projections materialize, 2.3 billion people will be added between 1975 and the year 2000, a far larger increase than the 1.5 billion added during the preceding 25 years. Given these population projections and the projected gains in income, every nonfarm claimant on cropland—urbanization, energy production, transportation—will be greater during the last quarter of this century than during the third.

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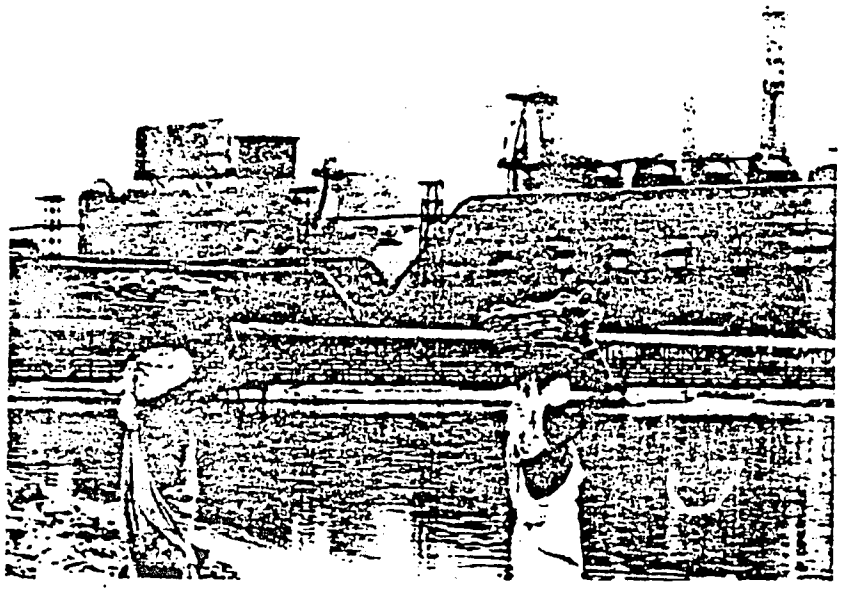
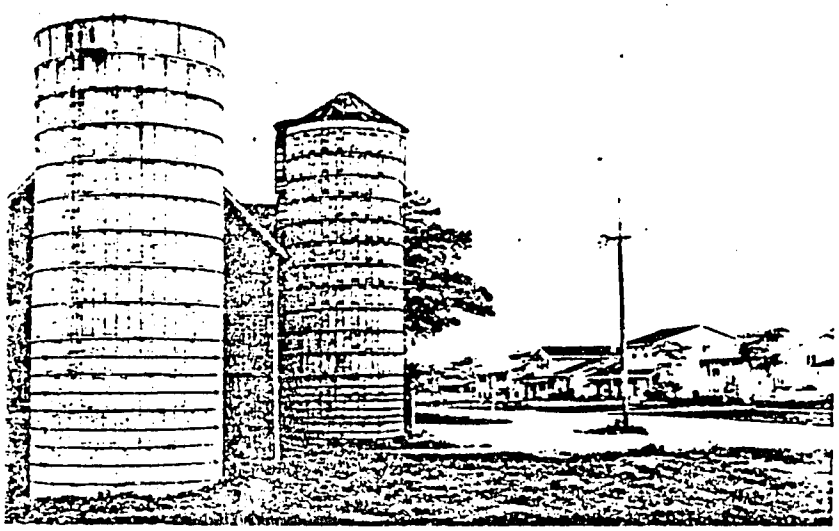


Industrialization in developing countries often comes at the expense of valuable cropland. This steel plant in India is the Burnpur Works of the Indian Iron and Steel Company. Photo: United Nations



Silos on an Illinois farm hold out—for the moment—against Chicago suburbs. Without land-use planning, productive cropland may continue to be swallowed up by the relentless growth of suburban development. Photo: USDA—Soil Conservation Service

Cropland Abandonment

Although the world demand for cropland is greater than ever before, the amount of cropland abandoned each year may also be at a record level. The reasons for cropland abandonment, usually the product of economic pressures interacting with ecological forces, include desertification, severe erosion, waterlogging and salinization of irrigated land, and the diversion of irrigation water to nonfarm uses.

Fed by the human pressures on their fringes—overgrazing, deforestation, and overplowing—virtually all the world's major deserts are expanding. As human and livestock numbers multiply, the creation of deserts or desertlike conditions is accelerating throughout Africa and the Middle East, and in Iran, Afghanistan, Pakistan, and northwestern India.

Documents prepared for the U.N. Conference on Desertification detail this expansion and the human creation of desertlike conditions. Some 630 million people, or one in every seven of the world's people, live in arid or semiarid areas. An estimated 78 million people live on lands rendered useless by erosion, dune formation, changes in vegetation, and salt encrustation. Desertification has deprived these people of their means of production, of their livelihood.

Soil erosion is an even more widespread problem. A report from the U.S. Embassy in Jakarta indicates that "soil erosion is creating an ecological emergency in Java. A result of overpopulation, which has led to deforestation and misuse of hillside areas by land-hungry farmers, erosion is laying waste to land at an alarming rate, much faster than present reclamation programs can restore it." Similar pressures are building in the rainfed agricultural regions of Pakistan. An AID officer in the Punjab area reports the annual abandonment of several thousand hectares of cropland because of severe erosion and degradation.

Severe gullying, which usually appears where subsoils are also erodible, is now common in many parts of the world. But it has received the least official attention in those countries where the process is most advanced. A U.N. report on soil deterioration and cropland loss in Latin America notes its serious dimensions in the Andean regions. Throughout the Andean countries, gullies are advancing through the steeply sloping countryside like the tentacles of a giant malignancy. As these gullies eat their way across fields, farmers who are already desperate for land continue to till what's left, right up the very edge of the gully. In so doing, they feed the gully, accelerating its progress across the countryside.

The irrigated lands that provide a disproportionately large share of the world's food are threatened both by ecological forces—waterlogging and salinity—and economic forces that divert water to competing uses. Waterlogging and salinity develop wherever surface water from rivers or streams is diverted to irrigate

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land that has inadequate underground drainage. This net addition to the natural underground water supply gradually raises the water table. Once the water table is within a few feet of the surface, the growth of deep-rooted crops is impaired and the early symptoms of waterlogging appear.

As the water table rises further, water begins to evaporate through the remaining few inches of soil, thereby concentrating the minerals and salt near the surface. Eventually the salt concentrations reach a level that prohibits plant growth. Glistening white expanses of heavily salted, abandoned cropland are visible from the air in countries traditionally dependent on irrigation, such as Iraq and Pakistan.

The problem is as old as irrigation itself. Indeed, the decline of some of the early civilizations in the Middle East is now traced to the waterlogging and salinity caused by their irrigation systems. Although the designers of the earliest irrigation systems in the Tigris-Euphrates Valley did not understand the subterranean hydrology well enough to prescribe corrective action, modern irrigation engineers do. A U.N. report, however, estimates salvage costs at $650 per hectare.

There are signs of waterlogging and salinity in many countries. Although fully half of the world's irrigation capacity has been developed since 1950, waterlogging and salinity are already impairing the effectiveness of many systems. The agronomic literature of China is liberally sprinkled with references to the problem. Heavy investments in agricultural land reclamation and irrigation in the Soviet Union during the 1970s have been aimed at improving drainage systems for the reclamation of irrigated land that has become waterlogged and salty. The more intensive irrigation in the Nile River Valley made possible by the Aswan Dam has upset the longstanding water balance in some areas, leading to the waterlogging and salinity of Egyptian soils that have historically been free of this problem.

In some regions, crop production is threatened not by too much irrigation, but by too little. The diversion of irrigation waters to other

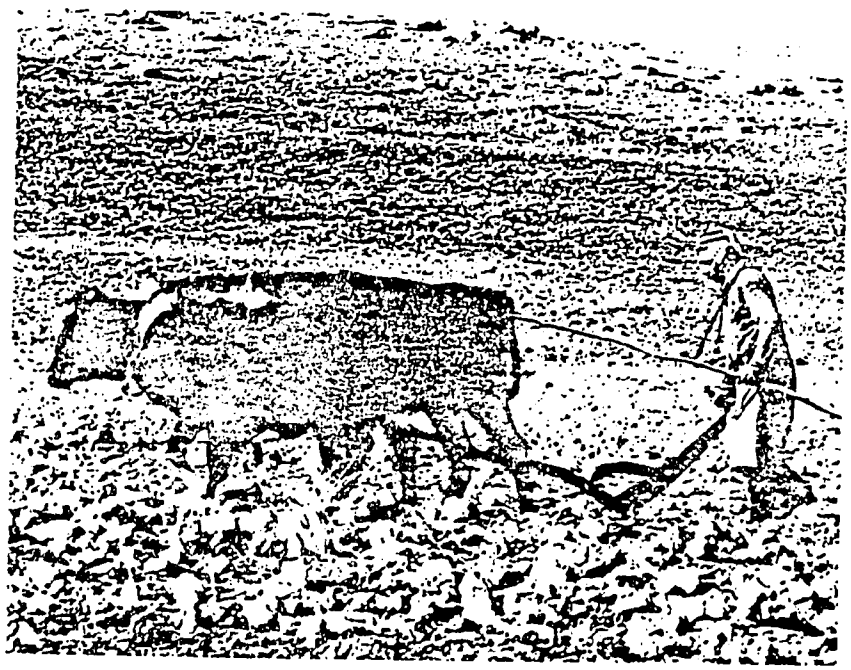
"Fed by human pressures on their fringes—overgrazing, deforestation, and overplowing—virtually all of the world's major deserts are expanding."

purposes is particularly a problem in arid areas with irrigated agriculture and with rapid urbanization and industrialization, such as the south central regions of the Soviet Union and the southwestern United States.

Soviet efforts to regain food self-sufficiency rest heavily on plans to expand irrigation. Consequently, investment in irrigation has been the fastest growing sector of the economy over the past 15 years. But irrigation plans and capital commitments may not be enough. Thane Gustafson, Soviet scholar at Harvard, reports that "the entire irrigation program is threatened because the southern half of the country is running short of water." Barring the massive diversion to the south of northward flowing rivers for irrigation purposes (a project that is now officially questioned on environmental grounds), severe water shortages appear to be inevitable.

In the United States, the problem has been carefully detailed for some of Arizona's leading agricultural counties. The irrigated area in Maricopa County is shrinking steadily as water is being diverted to the rapidly expanding Phoenix metropolitan area.

A similar situation exists in California, though on a much larger scale. As thirsty Los Angeles requires more and more water, the demand can often be satisfied only by diverting water from irrigation canals. Irrigated valleys that were once lush green have now turned a dusty brown. Fields that were once among the most productive in the world have now been abandoned. Urban needs, however wasteful or illogical, always take precedence over farm demands for water.



Peasant tills his field in Jordan. Most of the world's productive cropland is already under the plow. In many countries, land still available for cultivation often is infertile and vulnerable to erosion and deterioration. Photo: UNESCO/P.A. Pittet

Responding effectively to the threats to cropland associated with mounting food demands poses a dilemma for farmers and government planners alike. Both economic pressures and political instincts encourage a short-term focus, a desire to expand current output to satisfy immediate needs. But this pressure to wring more food out of the land can have devastating consequences for the soil.

The Thinning Layer of Topsoil

Over much of the earth's surface, the topsoil is only inches deep, usually less than a foot. Any loss from that layer can reduce the soil's innate fertility. Forty years ago, G. V. Jacks and R. O. Whyte graphically described the essential role of topsoil: "Below that thin layer comprising the delicate organism known as the soil is a planet as lifeless as the moon."

The erosion of soil is an integral part of the natural system. It occurs even when land is in grass or forests. But when land is cleared and planted to crops, the process invariably accelerates. Whenever erosion begins to exceed the natural rate of soil formation, the layer of topsoil becomes thinner, eventually disappearing entirely, leaving only subsoil or bare rock. Once enough topsoil is lost, the cropland is abandoned. But the gradual loss of topsoil and the slow decline in inherent fertility that precedes abandonment may take years, decades, or even centuries. Although this interim process does not affect the size of the cropland base, it does affect its productivity.

The U.S. Department of Agriculture's Soil Conservation Service reports that farmers are not managing highly erodible soils as well today as they were a generation ago. The adoption of conservation measures is relatively easy when there is excess capacity in the system; when grain prices are high and food is scarce, the temptation to forgo these essential measures is strong.

The Council for Agricultural Science and Technology, supported by a consortium of midwestern universities, reported in 1975 that "a third of all U.S. cropland was suffering soil losses too great to be sustained without a gradual but ultimately disastrous decline in productivity." A summary document prepared for the 1977 U.N. Conference

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"The decline of some of the early civilizations in the Middle East is now traced to the waterlogging and salinity caused by their irrigation systems."

Photo: Agency for International Development

Workers in Bangladesh build dams and canals in an effort to reclaim land and provide irrigation. Irrigation can increase productive cropland, but can also lead to problems such as waterlogging and salinization, which gradually lower the productivity of irrigated land.

on Desertification reported that just under one-fifth of the world's cropland is now experiencing a rate of degradation that is intolerable over the long run. The U.N. report estimated that productivity on this land has now been reduced by an average of 25%.

In the Soviet Union, attempts to regain food self-sufficiency through heavy investments in agriculture are stymied by soils that have lost some of their inherent productivity. The Nepalese government estimates that the country's rivers now annually carry 240 million cubic meters of soil to India. This loss has been described as Nepal's "most precious export."

In Ethiopia, the deterioration of soils was brought into focus by a drought that culminated in famine in 1974. A foreign ambassador in Addis Ababa described the origin of the problem in graphic terms: "Ethiopia is quite literally going down the river." More recently, the U.S. AID mission reports that "there is an environmental nightmare unfolding before our eyes. . . . It is the result of the acts of millions of Ethiopians struggling for survival: scratching the surface of eroded land and eroding it further; cutting down the trees for warmth and fuel and leaving the country denuded. . . . Over one billion—one billion—tons of topsoil flow from Ethiopia's highlands each year."

In a world facing an acute shortage of productive cropland, any loss of topsoil should cause concern. National political leaders and ministers of agriculture are faced with the task of adequately feeding an ever-expanding population without irreparably damaging one of the world's most essential resources—the soil. Mounting demand pressures, whether the subsistence survival efforts of Peruvian peasants or the responses of American farmers to market forces, can have the same effect. In a great many countries, efforts to produce more food are now leading to a slow but gradual decline in the inherent fertility of soils.

Land Productivity Trends

The ancients calculated yield as the ratio of grain produced to the seed that was planted. For them, the constraining factor was the supply of seed-grain. But as agriculture spread, and as seed became more abundant and land more scarce, the focus shifted from the productivity of seed to that of land.

From the beginning of agriculture until World War II, land productivity increased very slowly. For long periods of time it did not increase at all. Rice yields in Japan during the nineteenth century were only marginally higher than those during the fourteenth century. Corn yields in the United States during the 1930s were the same as those during the 1860s, the first decade for which reliable yield estimates are available.

Following World War II, however, crop yields began to rise rapidly in virtually every industrial country. During the 1960s, introduction of the fertilizer-responsive varieties of wheat and rice enabled yields in many Third World countries to also rise. From the end of World War II until the early 1970s, the steady rise in cereal yield per hectare was one of the most predictable trends in the world economy. Between 1961 and 1971, there were particularly impressive gains.

Since 1971, however, the increase has slowed; yields have become much more erratic and less predictable. From 1950 to 1971, the cereal yield per hectare climbed from 1.14 metric tons to 1.88 tons per hectare, or 2.4% per year. Between 1971 and 1977, the yield increased at only one-fourth that rate, or 0.6% per year. This marked slowdown was due to a combination of pressures, including the addition of marginal land to the world's cropland base, higher energy prices, a reduction in the land in fallow in the dryland wheat-growing regions, a shorten-

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Photo: Agency for International Development

Haitian workers rehabilitate an irrigation canal. Urban areas often compete with irrigated land for available water, and in most cases, the cities win.

ing of the fallow cycle in areas of shifting cultivation, and the cumulative loss of topsoil in major food-producing regions.

The agricultural yield per hectare turned downward unexpectedly in the U.S. and France during the 1970s; while in Egypt and China, it leveled off during this time. The reasons for the interruption in national yield trends are not precisely the same for all countries. The main contributor to the downturn in U.S. yield per hectare was undoubtedly the return to production of cropland previously idled under government programs. When participating in agricultural limitation programs, farmers invariably retire their poorest, least productive land. Since the United States is the world's leading food producer, bringing this poorer quality land back into production obviously had an effect on the world trend as well.

The high cost of energy has also influenced agricultural yields. The fivefold increase in the price of petroleum during the 1970s slowed the growth of energy use in agriculture. This influenced fuel use not only in tractors and irrigation pumps but also, indirectly, in the production of chemical fertilizer, an energy-intensive commodity. Fertilizer prices during the mid-1970s, influenced both by cyclical trends in the industry and by rising energy costs, soared to record levels.

A third influence on the productivity of cropland is a shrinkage in the fallowed area in dryland farming regions. As world wheat prices rose during the 1970s, U.S. fallow land dropped from 17 million hectares in 1969 to 13 million hectares in 1974. This decline led Kenneth Grant, head of the USDA Soil Conservation Service, to warn farmers that severe wind erosion and dust bowl conditions could result. He cautioned farmers against the lure of record wheat prices and short-term gains that would sacrifice the long-term productivity of their land.

Although the process of soil erosion is not always highly visible, its cumulative effects can also have a devastating impact on land productivity. Describing the effects of erosion in Nepal, German geographer Robert Schmid says, "During the last century, man in search of more arable land had greatly extended the terraced fields. . . . Increasingly, the farmers had to be self-sufficient, and therefore marginal land was taken into cultivation. . . ." The farming of increasingly marginal land, Schmid goes on, combines with progressive deforestation, as trees are felled for wood and branches are lopped from remaining trees for use as animal fodder, until a cycle of soil erosion and deterioration is set in motion. "On the permanently farmed fields the soil showed signs of exhaustion and the yields declined slowly."

In Canada, the inherent productivity of the cropland is being reduced by the continual substitution of marginal land for prime land. Land being lost to urbanization includes some of the most productive soils in the country, whereas that being added is far less productive. The net effect of substituting lower-quality land for higher-quality land lost to nonfarm uses is a reduction in the average fertility.

In summary, the outlook for raising cereal yields appears less hopeful now than it did at mid-century. A number of soil surveys and studies indicate that the inherent fertility of one-fifth or more of the world's cropland is declining. At the same time, the backlog of agricultural technology waiting to be applied in the agriculturally advanced countries appears to be dwindling. Together, these two factors cast a

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"Agricultural land can no longer be treated as a reservoir, an inexhaustible source of land for industry, urbanization, and the energy sector."

shadow over the prospect of a rapid, sustained rise in yield per hectare during the final quarter of this century to compare with that of the third quarter.

The Cropland Prospect

There is no simple way of projecting the cropland area for the remainder of the century, much less of assessing its adequacy. One way to gain some perspective on the cropland prospect, however, is to compare increases in population growth and cereal output for the third quarter of the century with those projected for the fourth quarter. Between 1950 and 1975, world population increased by 59%, or 1.5 billion. World cereal output increased by 97%, a near doubling. In 1950, there were still substantial opportunities for adding to the world's cropland base. The potential for expanding the area under irrigation was impressive and farmers had scarcely begun to exploit the potential for raising per hectare yields.

During the final quarter of this century, population is projected to increase by 58%, slightly smaller in percentage terms, but still an increase of 2.3 billion people—half again as many as the 1.5 billion added during the third quarter. As the final quarter of this century began, cropland was being lost to nonfarm purposes at a record rate. The abandonment of agricultural land because of severe soil erosion, degradation, and desertification was at an all-time high. The potential for substantial net additions to the world's cropland base was not good.

A review of the potential for expanding the world's cropland by geographic regions does not provide much ground for optimism. In North America, the cropland base has been shrinking for three decades. The Organization for Economic Cooperation and Development's Agricultural Committee reports that the opportunities for new land reclamation in Western Europe are negligible. The countries of Eastern Europe have been hard pressed to maintain their cultivated land over the last 15 years. In the Soviet Union, where farming has already extended into highly marginal rainfall areas, the prospect of further expanding the cropland base is not good.

In densely populated Asia, the prospect is not very bright either. There is little land to bring under the plow in China. In India, the region's other leading food producer, the cropland area is expected to increase little, if at all. But there is room to expand the area harvested through multiple-cropping, since much of the irrigation potential, particularly on the Gangetic Plain, is still to be developed. The one area in Asia that could sustain an increase in both cropland area and the intensity of cropping is the Mekong Valley and Delta, assuming that local political conditions permit these agricultural developments.

Photo: USDA—Soil Conservation Service

Erosion is not a pretty sight. Poor soil conservation practices often culminate in the destruction of valuable cropland. This barren field is near Valparaiso, Nebraska.

Although there are a few areas in Africa yet to be developed, overall there is limited opportunity for greatly adding to the cropland of the continent. In the vast northern section, the Sahara is reaching in every direction, claiming land in nearly a score of countries. The one country with potential for markedly expanding the area harvested is the Sudan, since it has developed only part of its share of the Nile waters, reserved to it by treaty with Egypt. To the south, the principal hope for more farmland lies in opening the tsetse fly belt to cultivation—if a way can be found to eradicate the tsetse fly.

In Latin America, the cropland area can be expanded by plowing up some grasslands, as Argentina has been doing during the 1970s. This would, of course, reduce the scope for grazing livestock. The other major potential, often overrated, lies in opening new lands in the interior of the continent, principally in the Amazon basin. The principal constraint here is the inherent poor fertility of the soil and its limited capacity to sustain cultivation over an extended period of time.

Wherever data are available, they invariably show a sharp falloff in the productivity of recent additions to the cropland base. This has been documented for countries as different as Canada and China. In effect, it confirms what some analysts have suspected—that the world's farmers have most of the productive cropland under the plow.

Soil is lost during spring run-off on a field in Brown County, Wisconsin. As long as soil loss does not exceed the rate of new soil formation, the soil's fertility and productivity can be maintained indefinitely. But a recent survey of Wisconsin soils found that 70% had greater-than-tolerable loss. Photo: USDA—Soil Conservation Service

The question of how much the world's cultivated area can be expanded has been hotly debated during the past 15 years. Some studies contend that it can easily be doubled, while others assume that the opportunities for adding new land will largely be offset by losses—leading to little, if any, increase in the cropland base.

On balance, it is difficult to see how the world can achieve much more than a 10% increase in cropland area during the final quarter of this century without a dramatic rise in the price of food. This area increase would be much smaller than the one that occurred during the third quarter of the century.

If this cropland assessment is a reasonable one, it suggests some serious difficulty in satisfying the projected growth in world food demand for the final quarter of this century. Projections of world food demand by the Food and Agriculture Organization of the United Nations and the International Food Policy Research Institute indicate or imply that the world demand for food will roughly double between 1975 and 2000. Assuming the modest growth in the cropland area of 10%, satisfying the projected growth in demand would require an even greater increase in yield per hectare during the final quarter of this century than was achieved during the third quarter.

Unfortunately, recent trends indicate the potential for a continuing rapid rise in crop yield per hectare may be much less than has been assumed in existing projections of world food supply. The postwar trend of rising yield per hectare has been arrested temporarily in the United States, France, and China, each the leading cereal producer on its respective continent. Aside from the biological constraints on raising crop yield per hectare, a combination of pressures to extract ever more food from the land and poor land management is leading to the slow but progressive deterioration of an estimated one-fifth of the world's cropland.

This review of the period from 1950 to 1977 indicates a clear loss of momentum during the 1970s in the efforts to raise worldwide food consumption. Since 1971, output has

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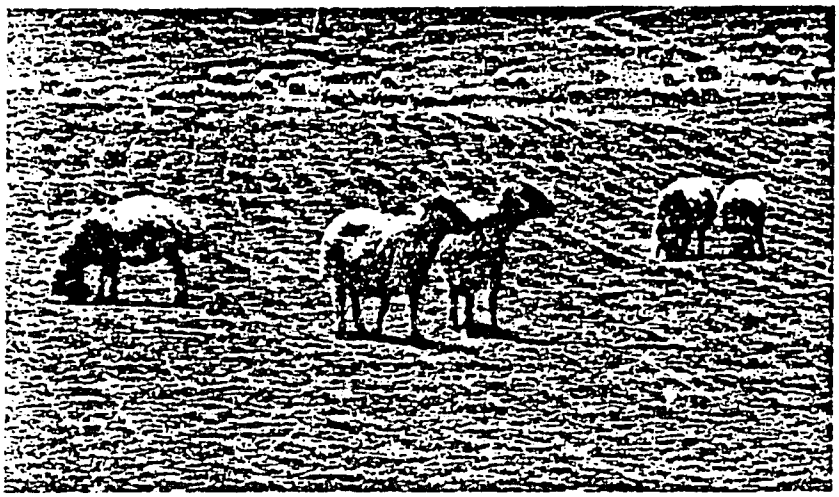

Overgrazing is a significant contributor to soil erosion. These sheep are grazing on a field in Jordan. Photo: FAO

failed to keep pace with population growth, much less the growth in demand generated by rising incomes. The result has been rising food prices. If the cropland assessment is reasonable and if the projected increase in world population materializes, then steep rises in food prices in the years ahead may be inevitable.

The years from 1972 to 1976 were ones of insecurity and instability in the world food economy unprecedented in peacetime. During the late 1970s, however, uncommonly favorable weather and stepped-up food production efforts may be lulling the world into a false sense of complacency. The dimensions of the emerging stresses are likely to come into focus the next time two or more of the major food-producing countries have poor harvests. Just as years of bad weather tend to bring a deteriorating situation into focus, so recent years of good weather have tended to obscure the long-term deterioration.

Public Policy Implications

Few things will affect future human well-being more directly than the balance between people and cropland. If recent population and cropland trends continue, that balance will almost certainly be upset, leading to economic uncertainty and political instability. Avoiding large, politically destabilizing rises in food prices between now and the end of the century may not be possible without a mammoth effort to protect cropland from nonfarm uses, to improve the management of soils, and, most importantly, to quickly reduce the rate of population growth.

Agricultural land can no longer be treated as a reservoir, an inexhaustible source of land for indus-

"The times call for a new land ethic, a new reverence for land, and for a better understanding of our dependence on a resource that is too often taken for granted."

try, urbanization, and the energy sector. In a world of continuously growing demand for food, it must be viewed as an irreplaceable resource, one that is paved over or otherwise taken out of production only under the most pressing circumstances and as a result of conscious public policy.

Historically, land in most countries was allocated to various uses through the marketplace, but unfortunately the market does not shield cropland from competing interests. As cropland becomes more scarce, it can be protected from competing nonfarm demands only through some form of land-use planning.

The OECD reports that Japan is the only country with comprehensive zoning nationwide. In 1968, the entire country was divided into three land-use zones—urban, agricultural, and other. Given the acute pressures on its land resources, Japan has faced the issue first and in so doing has developed a model for other countries to follow.

Within the United States, national land-use planning is still at a rather rudimentary level, confined largely to setting aside national parks, forests, and wildlife reserves. At the local level, there are often restrictions on land that can be used for commercial purposes.

During the 1960s, several European countries—Belgium, France, Germany, and the Netherlands—passed legislation establishing land-use guidelines, with planning to be done at the local level.

Rivaling the loss of cropland to nonfarm uses is the process of gradual soil degradation through erosion. If the loss of topsoil and associated soil degradation are permitted to continue, they will lead to ever higher food production costs. But the effort needed to halt the deterioration of the soils on which humanity depends is staggering, one fraught with complicating social factors.

The one source of cropland degradation and loss officially dealt with at the international level is desertification. The World Plan of Action to stop the spread of deserts, agreed to at the Nairobi conference, concluded that money spend now to halt and reverse desertification and the loss of cropland promises high returns, ones that are competitive with other forms of investment. But achievement of a net zero desert growth will be possible only with prompt, concerted action by national governments that are, unfortunately, not usually noted for such efforts.

In many countries, the stabilization of soils is such a vast undertaking that it will require a strong national political commitment and a detailed plan of action. Such a program has been outlined for the United States by the Soil Conservation Service. In order to stabilize U.S. soils and bring the annual loss of topsoil down to a level that does not exceed the tolerance factor, the plan calls both for changes in cropping practices and for heavy investments in land improvements. However, these prescribed changes in farming practices are monumental in scale, involving half of all U.S. cropland. Adoption of these soil-saving measures would often run counter to the immediate economic interests of farmers and consumers, since they would lead to a 5 to 8% increase in food production costs. Some efforts to conserve soil and protect long-term food production might reduce food output in the near term as well.

But, the future balance between people and cropland is likely to be affected more by population policy than by any other single factor. Growth in human numbers not only generates a demand for more cropland, but it also simultaneously generates pressures to convert cropland to nonfarm uses. Thus far, policymakers have assumed that projected increases in population over the final quarter of this century will materialize. But the social costs of remaining on the projected demographic path may become too great. A fundamental rethinking of population policies at the national level may well be unavoidable in many countries.

The changing food prospect may lead to the abandonment of pronatalist policies and the active encouragement of small families. Other governments may join those of China and Singapore in advocating a maximum of two children per couple and in making family planning universally available. With future rates of population growth bearing so heavily on the prospect of eliminating hunger, the fact that one-half of the world's couples do not yet have access to family planning services is not only socially irresponsible, but politically inexcusable as well. If population growth is to be reduced to a socially acceptable rate, unprecedented changes in government policies and in individual attitudes will be required. Such changes are not likely to occur without a better understanding of the precarious balance between people and cropland.

The convulsive changes in the world food economy during the 1970s reflect in part the growing pressures on the cropland base. They should be regarded not as an aberration, but rather as a signal that pressures on the cropland are in some ways becoming excessive. They may in fact be advance tremors warning of the quake to come.

The issue is not whether the equilibrium between people and land eventually will be reestablished. It will be. If the deterioration is not arrested by man, then nature will ultimately intervene with its own checks. The times call for a new land ethic, a new reverence for land, and for a better understanding of our dependence on a resource that is too often taken for granted.

This article is based on *The Worldwide Loss of Cropland* (Worldwatch Paper 24, published by the Worldwatch Institute, Washington, D.C., 1978). The complete report is available for $2.00 from the World Future Society Book Service.

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Rural Land Use Planning,
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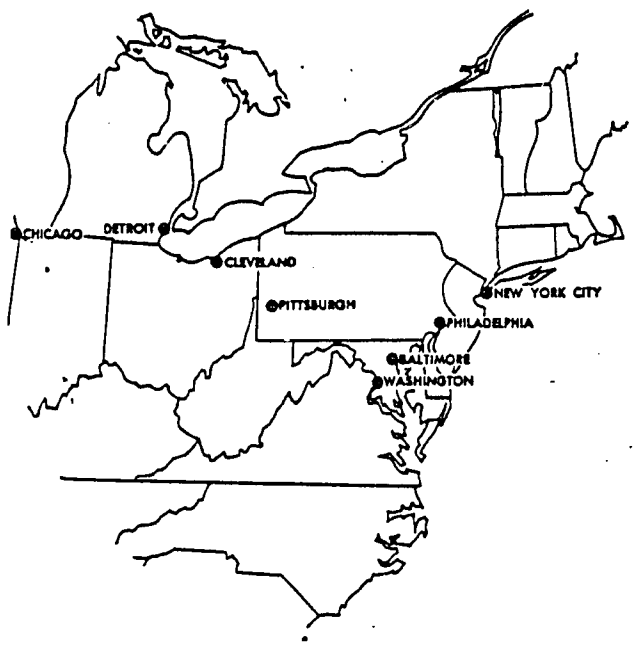
RURAL LAND USE PLANNING

W. M. Carroll, R. G. Wingard, C. J. Wingfield

Pennsylvania is near the center of the world's greatest consumer market. Seven of the 10 largest U. S. cities and about 100 million people are within a 500-mile radius. There are both large metropolitan areas and wide expanses of open country. The urbanized areas centered around Philadelphia and Pittsburgh contain 5.4 million people. Another 3.2 million live in smaller cities. But within 100 or 200 miles of these urban centers, large areas of wooded, mountainous terrain support one of the largest big-game populations of the country, a variety of small game, and numerous streams in which game fish still hold their own. Approximately 17 million acres out of a total state acreage of 28.8 million are in forest or in open land not used for agriculture.

About 9 million acres of the state are in crops and pasture. Though farm output in Pennsylvania is increasing gradually, production is being concentrated on the better soils, and some less productive land becomes available for other use each year. Land has also been released from oil and mining; some of it, especially in strip mining areas, presents special renovation challenges. Improved highways, large nearby markets, and a plentiful water supply make resource development in many areas a real possibility. It is already evident, however, that demands for water for industry, domestic consumption, farms, recreation, and other purposes will make conservation and planned use of water even more important.



Pennsylvania is faced with the problem of how best to develop its land, water, forest, and wildlife resources. One facet of the problem is how to create new land uses or expand old ones that will be attractive and useful to nearby urban populations. Another facet is how to guide or control diverse uses of land so that desirable combinations are obtained, with a reasonable reconciliation of private and public interests in the land. Unplanned growth in some communities is forcing local governments to make decisions as to how to preserve land uses the community wants and to guide future development along more satisfying lines.

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The resource development question is not new nor is it unique to Pennsylvania. However, here the close association of a large urban population, a substantial agriculture, extensive forests, magnificent scenery, and large areas of land suited to industrial, commercial, residential, and recreational development create both immediate opportunities and recognized difficulties to a degree found in few other states.

Planning for growth

Land use planning lies at the very heart of a resource development program. Sustained growth and development cannot be accomplished without sound, effective planning. The fact that we are concerned with planning means that we are placing emphasis upon the future. It implies that we are dissatisfied with the present state of events or future prospects and that we are willing to make changes or plan for the future to achieve a better outcome.

Effective planning must be forward looking. It involves more than a survey and analysis of development accomplished at a point in time. It involves more than a portrayal of trends which have occurred in major economic magnitudes through the past. It involves more than a projection of trends into the future. While sound effective planning involves all of the above, in addition, it involves conscious efforts to guide the course of future events to help achieve desired objectives. The break-through to a more rapid rate of development typically involves changes in social organization and philosophy. It involves purposeful action by governments as well as an enlightened and dedicated citizenry.

Why plan

The justification for public planning and zoning rests upon an assumption of public responsibility for the protection and promotion of health, safety, morals, and the welfare of the community. These are among the most fundamental of local government's powers. All of Pennsylvania's local jurisdictions have them. As citizens in a free society, we must face up to the responsibility and fact that our communities are what we have made them. They are no better nor worse than their citizen decision-makers made them — either by deliberate or inadvertent action or inaction.

A specific judgment made today may have long-range consequences for matters seemingly unrelated. For instance, a public decision to construct a trunk sewer or build a street or highway may dictate industrial or commercial land-use for years into the future or make a residential development uninhabitable. A decision (or the failure to make a decision) concerning disposition of sewage may pollute streams and rivers to the point that they are not only useless, but actually harmful. The location of a cheap residential housing development in a choice industrial tract may thwart development of the economic base forever, or at best make it unnecessarily costly. The failure to plan for adequate recreation, education, open space, or general physical or cultural harmony may frustrate community progress. What we — public and private — do and don't do today clearly shapes and limits available alternatives tomorrow.

What is planning designed to do?

Public planning is a process for making rational decisions about future actions aimed at the attainment of community goals. Goals will vary from community to community and according to the group or individual interpreting objectives. However, it can usually be assumed that most communities are interested in providing a healthful, efficient, convenient, and attractive environment in which their people may live.

With a system of democratic government, the peoples' wishes are manifested through their elected representatives. Planning is merely a tool in the hands of these community leaders. It can effectively be used for the area's best interests. There is no magic in the process, but it does greatly facilitate a very difficult job. It is a vehicle whereby responsible citizens may assess the community's physical needs, both present and future and lay plans for their satisfaction on a priority basis. To be effective, a plan should in-

clude all phases of community life. It should be concerned with devising and bringing to reality the most satisfying land-use pattern, while coupling physical design with a program of community services geared to the peoples' needs and desires.

The plan, once in effect, is used as a guide or "yardstick" by which future proposals may be judged. The plan is not a static instrument and should be flexible enough to adapt to an ever changing community situation. This means that the preparation of a formal plan is only the first step in a much broader process. The success of the planning effort is more likely to be determined by the quality of political, administrative, and technical leadership charged with the task of working with the plan than the basic document.

The plan is a community compass. It indicates a predetermined course the community has chosen to follow. In that sense, it is a navigation tool. The course charted depends upon the wishes of the community. No two communities need follow the same course. The plan represents a compass heading that leads to the goals sought by the community. Without the plan, it is difficult to know whether a community is heading in the desired direction, or if headed properly today, whether it will wander off course tomorrow. This does not mean that once set the course cannot be altered. Like the ship at sea, when there are impelling signs to suggest change someone in command and armed with adequate information and authority must make the decision to alter course. Here again, the plan is a useful tool for providing the needed information.

Implementing tools

After the comprehensive plan is complete and the best courses of action selected, the sizable task of bringing the plan to life still lies ahead. Various practices and instruments are at the planner's disposal for this purpose.

Zoning is the most widely used method of enforcing the land-use aspects of the comprehensive plan. Some patterns of land-use are more desirable than others. Zoning is a legal and administrative process whereby the community protects itself against indiscriminate land uses. In technique, zoning is a simple division of land into districts having different kind and extent of use and density regulations. It is an instrument for guiding the use of land in the future and protecting existing uses which conform to the over-all aims of the comprehensive plan.

Purposes of Zoning

1. Lessen congestion in the streets.
2. Secure safety from fire, panic, and other dangers.
3. Promote health and safety.
4. Prevent the overcrowding of land.
5. Avoid undue concentration of population to facilitate adequate provision of: transportation, water, sewage, schools, parks, and other public requirements.
6. Promote the general welfare and morals.
7. Conserve the value of property.
8. Encourage the most appropriate use of land throughout the jurisdiction.

Accomplished by:

1. Regulating height, number of stories, size of buildings.
2. Regulating the percentage of a lot that may be occupied by a building.
3. Specifying the size of yards, courts, and other open spaces.
4. Controlling the density of population by use in relation to lot size.
5. Regulating location and use of buildings, structures and land for trade, industry, residence or other purposes.
6. Dividing municipalities into districts of such number, shape and area as may best be suited to carry out the purposes of land-use planning.

Subdivision control, like zoning, serves as a preventative measure guarding against improper lot layout and inadequate subdivision preparation. Such ordinances can be especially useful in areas experi-

encing rapid growth. In the long run, the community, the future homeowner, and the developer will all benefit from a fairly administered, well-planned subdivision control program. A well-planned subdivision usually means a better place to live for homeowners, lower public service costs, and added profits for developers. Everyone gains from good design.

Various codes are also necessary for effective administration of a comprehensive plan. These codes establish certain minimum requirements with which builders and owners must comply. Experience has shown that a properly constructed building will last longer and be safer, be of greater use to its occupants, and contribute to a more beautiful and valuable community. These minimum specifications deal with such features as building size, setback requirements, safety factors, plumbing, and electrical installation.

Land use changes are not restricted to the urban and suburban communities, although development in these areas is most dramatic. Changes in ownership and pressure on the use of land extends into the most rural, forested, and isolated areas. Citizens from both urban centers and rural areas are placing increasing, and often conflicting, demands on farm and forest land for its benefits. Much of this pressure on land and water can be attributed to more people, income, leisure, and interest in all forms of outdoor recreation. In response to these demands, there is much interest throughout the State to promote and develop land and water resources.

Land use changes will continue

Without planning and coordinated development the change of a million acres into urban and built-up areas could be excessively wasteful of land that normally would provide open space and outdoor recreation opportunities. The amount of land occupied by these new developments is not nearly so important as the pattern and location of the changes. We need and want new homes, schools, improved highways, and other facilities for more people. There is a choice in where and how these changes are located to take advantage of all resources and to avoid excessive waste of limited land and water resources. Many of these choices will be made by group decision. Land-use planning which recognized the natural resource advantages of the State and the high demand for space for outdoor recreation could help guide these future changes in land use. Without planning we can expect heavy loss of our wildlife and other recreational opportunities in the future.

Residential areas

Many problems of farmers result from the urban explosion. More urban dispersal into rural areas is certain. Land will be needed for homes, highways, commerce, and industry.

Farmers will serve the best interest of agindustry and of the total economy by supporting comprehensive land-use planning, which includes the development and protection of desirable residential districts.

Less fertile soils are often most suitable for residential uses. Areas free from floods with well-drained soils are essential. Unless sewers are available, tight soils should be avoided. A better view is possible on sloping land.

Business and industry

Land and water will continue to be needed for business and industry. Ribbon business districts often cause traffic congestion, increase road hazards, and increase the assembly costs of trucks picking up dairy products, poultry and eggs, and fruit and vegetables from farm operations.

Neighborhood shopping centers of about a dozen stores and the larger regional shopping centers that provide convenient off-street parking space appear to be winning favor.

Industry needs areas with adequate water, sewage, and power facilities. It needs land that is level, free from floods, and well-drained. Transportation facilities, fire and police protection are essential.

Farming areas and rural communities need to protect the best industrial sites for business and industry. These will be needed for expansion of the employment

base, the tax base and markets for farm products.

Comprehensive land-use planning offers a way to permit cities and farms to prosper and grow.

Wildlife recreation may conflict

When residential development leapfrogs open areas it creates idle land that may be neither town nor country. Wildlife produced on these lands is often a liability rather than an asset. There may be problems of wildlife damage, problems of law enforcement of unauthorized hunting, and high risk to the motoring public when wildlife-automobile collisions occur. Hunting is dangerous not only within towns and cities, but wherever scattered subdivisions and unplanned development takes place. This is evident from the fact that over 100 townships of the State, some fairly rural in character, have enacted ordinances to control or restrict hunting because of safety hazards and land uses that conflict with wildlife.

Public recreation lands

There are many land use arrangements which have been developed to accommodate access and use of land and water for hunting, fishing, and other forms of recreation. Public land ownership has become a symbol of recreational land use. Federal, State, and local governments provide land and water in Pennsylvania for public recreational use. Even on public areas there may be certain restrictions or controls placed on the user, such as where, when, and under what conditions use is permitted. But in general, public lands are open to easy access and use.

Pennsylvania has a fine system of about three and one-half million acres of public lands, and a hunting rights lease program involving about two and one-half million acres of private farm land. Access, development, and use is in good order on these public and leased areas.

Public use of private lands

On publicly owned or leased areas there is no problem of access and use by the public. The costs of ownership, lease, management, development and use are handled as a function of government through li-

How to do it

Traditionally, the popularly elected legislative body has delegated the responsibility for planning to a citizen planning commission. In Pennsylvania, the commission is usually composed of five members, who are appointed by the local legislative body for staggered terms. A planning commission is a necessity for any community wishing to plan in a serious manner.

The commission members receive no compensation for their services. They are selected to represent the entire community and should refrain from alignment with any particular special interest group. Planning commission members must be willing to devote long hours to their responsibilities. The success of the planning program may well rest upon their interest and ability.

The planning commission is an advisory board to the legislative body and should exercise care not to exceed this role. However, it is equally important that the planning commission not operate in a political vacuum. The commission must remain in contact with the legislative body and must keep it informed of planning progress and problems.

Intelligent law making at any level of government requires a certain amount of background staff work. The planning commission can serve to fulfill this need on all issues logically associated with planning. Conversely, the legislative body of the community must consciously work to take full advantage of the planning commission's knowledge and experience and to keep planning commission members informed of pending issues and legislative wishes. All too often, a planning commission cannot adequately perform its job because it has become isolated by the governing body's indifference or its own autonomy. It is also important that operating departments cooperate with the planning commission in departmental program planning and to supply certain specialized information needed in the planning process.

Countywide planning is of value not only to the county unit of government but also to the townships, boroughs, and cities within these counties. As urban areas spread into rural areas it is almost impossible for each city, borough, or township to plan its future development as though it were an island. In a time

of great mobility where members of one family will farm, work, play, shop or go to school in several different governmental jurisdictions during the course of a single day's activity, the local government unit must view its development as part of a region or watershed. County planning can serve as a coordinating framework for local planning, enabling local planning commissions to see their problems more clearly.

Properly financed and staffed county planning units can also be of great value by providing a source of continuing technical services to local planning commissions. Such service has proven an efficient and economical method of obtaining the continuing technical help which all planning commissions require for effective operations.

Citizen participation

A comprehensive plan is created and exists for the welfare of the general public and it can never succeed without enjoying the support of the majority of the citizens. This need is partially met by means of the citizen planning commission. This commission serves a dual purpose in that citizen opinions are expressed and at the same time, the citizens are drawn into the planning process. An otherwise sound plan may fail where citizens are not kept informed. There is little doubt that public relations can make or break a plan, and a considerable amount of time and effort must be spent merely explaining the program to the people who have the final say as to whether a plan will be adopted. The citizen benefits from and must pay for the service. It is proper that his approval be required.

Intergovernmental cooperation

Pennsylvania communities may cooperate in almost every activity they are authorized to undertake alone, through the use of the interjurisdictional agreement. For those who support strong local government, intergovernmental cooperation through the interjurisdictional agreement has the advantage of being started at the local level. Local officials can retain responsibility and flexibility of operation while benefiting through increased efficiency and financial savings.

Small units of government such as townships often find it financially impossible to provide certain services for their residents. High costs are encountered and often large capital investments are required when services must be provided for a relatively small number of people or a relatively small area of land.

Joint community action can bring results, especially in providing water resources, sewage and refuse disposal, police and fire protection, and in planning and zoning. Services often can be provided of a quality and quantity beyond that which a single community could provide alone. Cooperation can eliminate duplication of effort, making government lower cost and more efficient.

The Pennsylvania State University encourages the discussion of public issues by interested groups as part of the Agricultural Extension Program. Your County Agricultural Extension staff can give assistance in planning and conducting such educational discussions.

Source: Environment, Vol. 22, No. 4, May, 1980

FOOD VERSUS FUEL

Competing Uses for Cropland

This new interest in fuel crops could be a historic landmark. If more and more oil refineries are replaced by alcohol distilleries, the world agricultural economy will be transformed. Although the production of industrial crops, such as cotton, is almost as old as agriculture itself, it has never occupied more than a minute percentage of the world's cropland. Now, with the introduction of fuel crops, the possibility exists for the first time of a major shift of food production capacity to nonfood purposes. The potential demand is virtually limitless: even converting the entire world grain crop to alcohol would not provide enough fuel to operate the current world automobile fleet.

The attractions of an agriculturally based alcohol fuel industry notwithstanding, there are many problems to be considered. The increased production of energy crops will intensify pressures on the earth's cropland—pressures that are already excessive in many parts of the world and that have led to extensive erosion and soil deterioration. Even without the diversion of agricultural production capacity to energy crops, efforts to expand world food production have been losing momentum for nearly a decade. And although the rate of world population growth did slow slightly during the seventies, from 1.9 percent in 1970 to 1.7 percent or less in 1979, the absolute increase in world population continues at around 70 million per year, steadily adding to the number of people to be fed.[2]

The demand by motorists for fuel from energy crops represents a major new variable in the food/population equation. The stage is set for direct competition between the affluent minority, who own the world's 315 million automobiles, and the poorest segments of humanity, for whom getting enough food to stay alive is already a struggle. As the price of gasoline rises, so, too, will the profitability of energy crops. Over time, an expanding agricultural fuel market will mean that more and more farmers will have the choice of producing food for people or fuel for automobiles. They are likely to produce whichever is more profitable.

National Energy Plans

Among the countries already producing ethanol for fuel or actively considering it are Brazil, the United States, South Africa, New Zealand, and Australia. Within this group Brazil is the unquestioned leader. It has moved rapidly to develop and implement a national alcohol fuel program, based principally on sugarcane.

Brazil

Ethanol's potential as a fuel was recognized in Brazil from the early days of the automobile, but it was never competitive with cheap petroleum even when it was produced as a by-product of sugar manufacture. Brazil relies on imports for 85 percent of its oil, yet the country has based its vast transportation system—which has to serve the fifth largest land mass of any country in the world—on highways and motor vehicle transport. By mid-1979 Brazil was [illegible]ing an estimated $6.5 billion [illegible]y on oil and importing nearly [illegible] million barrels a day.[3]

Brazil's alcohol fuel program was launched in 1975. At that time, the goal was to become self-sufficient in automotive fuel by the end of the century. After the Iranian revolution and the associated increases in the world price of oil during early 1979, the government accelerated its alcohol fuel program. Although official goals beyond 1985 are rather vague, the actions taken suggest a desire to be self-sufficient by the end of the eighties.[4]

Between 1975, when it was launched, and 1985, an estimated $5 billion will pass through the National Alcohol Program as subsidies for production and consumption of alcohol fuel. Government incentives take the form of concessionary financing to help modernize and expand existing alcohol distilleries, to build new distilleries, and to develop the agricultural projects to supply them.[5]

From 1975 to 1979, alcohol production increased from 640 million to 3 billion liters (790 million gallons). In 1979, alcohol accounted for an estimated 14 percent of Brazil's automotive fuel consumption, most of it as gasohol. But in 1980, when it is expected to constitute 20 percent of the total, some of it will be used in new cars designed to run exclusively on alcohol. The exceedingly rapid growth in alcohol production and use reflects the existence of both a dynamic entrepreneurial class in Brazil and strong government support.[6]

Industry sources within Brazil believe they can produce 20 billion liters of alcohol for fuel by 1985, enough to provide 60 to 70 percent of the fuel requirements of the projected automobile fleet of 12 million vehicles. Government officials are less optimistic. They project a production of just under 11 billion liters of alcohol by 1985.[7]

The ambitious Brazilian alcohol fuel program is based largely on sugarcane, the most efficient of all energy crops. Sugarcane currently yields 388 gallons of alcohol per acre, nearly 65 percent more than corn, the major distillery feedstock in the United States. Although only 2 percent of Brazil's total land area would need to be planted to sugarcane to achieve the goal of automotive fuel self-sufficiency, this would equal half the total land area currently planted to all crops.

Although the overriding objective of the Brazilian alcohol fuel program is to rid the country of dependence on imported oil, there are other goals. The government hopes that by creating jobs for presently unemployed rural workers on land that is now unused, the program will help stem the tide of urban migration, improve the country's skewed income distribution, and foster more balanced development throughout the country. But the key to achieving these goals may lie in the successful adoption of manioc as an alcohol feedstock, because manioc can be produced by smallholders on the marginal land most common in the least developed regions of the country.[8]

New Zealand

Another country that has carefully examined the potential for producing liquid automotive fuel from agricultural commodities is New Zealand. The most likely feedstock for alcohol distilleries there would be a type of sugar beet or fodder beet. The New Zealand Energy Research and Development Committee reports that "it is technically possible to provide all road transport fuel which present projections say New Zealand will require in 2000" from energy crops. In examining the balance-of-payments consequences of moving toward energy crops as a source of road transport fuel, the committee notes that "energy farming could save as much as $2 of foreign exchange for every $1 of foreign exchange earnings lost by way of displaced agricultural production." What this particular calculation does not reflect, of course, is the impact on food prices outside New Zealand if such a strategy were to be pursued. The authors of the study conclude that "energy farming is one alternative which offers New Zealand a much more secure supply of transport fuel at a cost that is less dependent on international politics and other factors beyond our control."[9]

Achieving transport fuel self-sufficiency in the year 2000 would require New Zealand farmers to plant between 700,000 and 1.3 million hectares of fodder beets, sugar beets, or corn. This compares with a total current cropland area in the country of 835,000 hectares. In effect, New Zealand would need to at least double the current area under crops if it were to become fuel self-sufficient without taking land that is already being used to produce food.[10]

Australia

In Australia, which ranks third behind the United States and Canada as an exporter of cereals, a strong commercial interest in liquid fuels is beginning to emerge from the private sector. Australia's AMPOL Petroleum Limited and Biotechnology Australia Proprietary Limited have calculated that within five years Australia could be producing 15 to 20 percent of its fuel for motor vehicles in the form of alcohol distilled from wheat. The two firms estimate that satisfying that amount of motor fuel needs would require roughly as much wheat as Australia currently produces.[11]

The two companies have joined forces to begin operating a pilot plant at a former brewery in Sydney. They plan to use the continuous fermentation process for producing alcohol rather than the batch fermentation process that is used in Brazil and elsewhere. The pilot plant will not only test the process, but will also give the companies better data on costs. The managers of the joint project hope continuous fermentation will mean they can produce 440 million gallons a year within five or six years—enough to satisfy one-tenth of the Australian gasoline market. During the early years of the project they believe grains will be the most desirable feedstock for alcohol manufacture.[12]

An Australian study undertaken by the Commonwealth Scientific and Research Organization analyzed liquid fuel prospects and reported that Australia could get almost three-quarters of its transport fuel from crops, crop residues, and forest products. Such waste materials as cereal residues, bagasse from sugarcane, and forest refuse alone could produce as much as 1.3 billion gallons of alcohol. Seen against Australia's current annual consumption of just under four billion gallons of gasoline, this could make a significant contribution.[13]

Austria

Yet another country that has recently looked at the production of automotive fuel from crops is Austria. During the late seventies, Austria's population stopped growing but its agricultural output continued to expand, with the result that it is now producing an exportable surplus of grain. The grain surplus, totaling 200,000 to 300,000 tons per year, is being exported to Eastern Europe, principally Poland, which is eager to take the grain. But exporting wheat poses a fiscal problem for Austria as the domestic wheat price is well above the world market price. Each ton of wheat that was exported during 1978/7 was subsidized at the rate of $84 per ton.[14]

The Fuel From Biomass Project, sponsored by the Austrian Ministry of Science and Research, has seized upon this exportable surplus of grain as a potential source of alcohol for fuel. As a result, Austria is now seriously con-

sidering the construction of a small demonstration plant to convert grain into fuel-grade alcohol. The distillers' grain remaining after the fermentation is slated for use as a high-protein feed for livestock, which would reduce the demand for imported soybean and fishmeal.[15]

South Africa

South Africa, which currently leads the world in the production of liquefied fuel from coal, also has a large project to produce alcohol from crops. It is planning to use both cassava, which is a dietary staple in many parts of Africa, and sugarcane as raw materials for the production of alcohol. Current plans call for converting the Makatini Flats in northern Zululand, a semiarid plain with sparse vegetation, into cassava plantations. South Africans talk of converting this arid plain into an "oil field."[16]

The South African cassava project as outlined is exceedingly ambitious. Involving huge plant nurseries that will produce cassava seedlings through a rapid cloning process, it calls for some 13 ethanol distilleries in the Makatini Flats area. These would produce 137 million gallons of liquid fuel annually and employ a total of 2,600 people in cassava production and alcohol distillation. It is also being promoted by the South African government as a way of encouraging rural development. To the extent that cassava can be grown in areas that were not producing anything of agricultural value and with resources that would not otherwise be used to produce food, these new "oil fields" will not compete with food crops.[17]

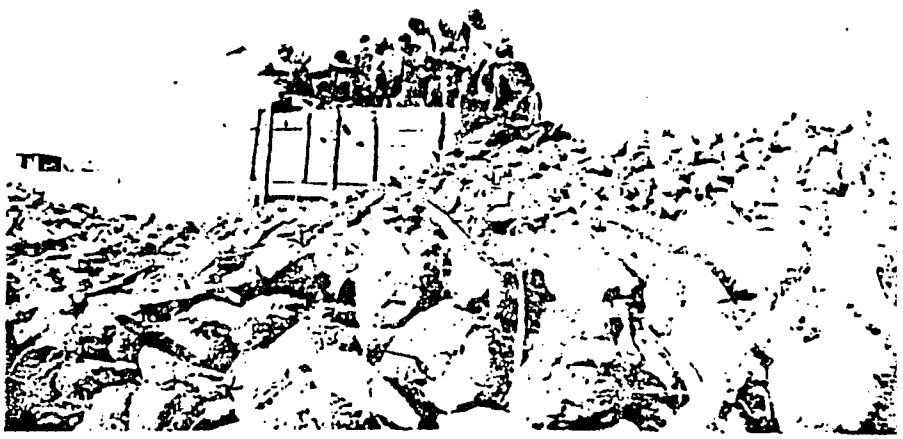
The sugarcane part of the South African alcohol fuel project, however, would compete directly with food crops. Indeed, in order to encourage greater sugarcane production, the government is guaranteeing water supplies to farmers who will grow sugarcane explicitly for the production of alcohol. Under this arrangement, sugarcane grown as an energy crop would in all likelihood divert both land and water from food production.[18]

South Africa is also the site of another innovative experiment in liquid

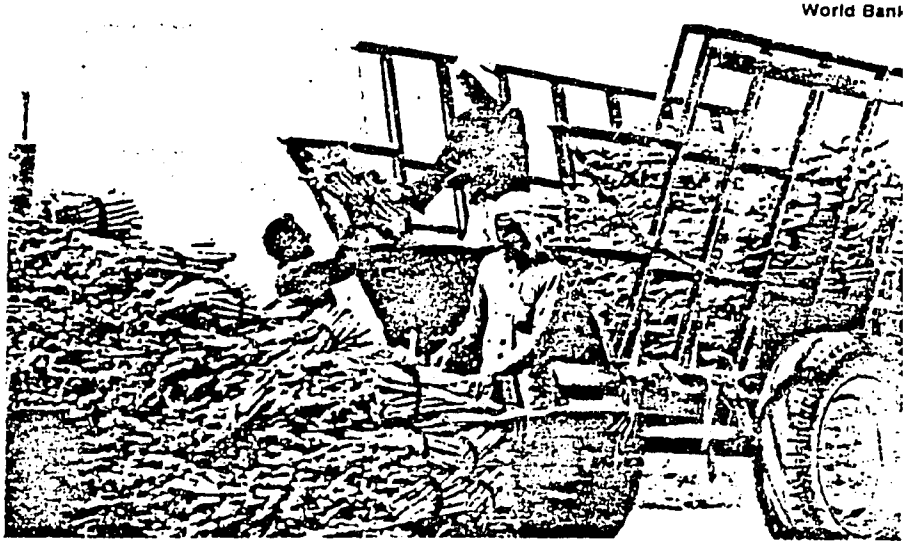
THREE SOURCES OF ALCOHOL FUEL

Alcohol distilled from farm commodities is being widely examined as a source of fuel, particularl for automobiles. Below are three crops—sugar beets, sugar cane, and corn—that are central to suc plans.

World Ban



World Bank



USDA-Soil Conservation Service

74

fuels. The Department of Agricultural Technical Service is conducting a pilot project using sunflower oil as a fuel substitute in diesel-powered tractors. Sunflower seed oil apparently has worked well in the first 100 hours of trials in a diesel engine. If this experiment should prove successful, it is estimated that corn farmers could grow enough sunflowers on just 10 percent of their land to provide all the fuel for their tractors.[19]

Other Interested Countries

Although the national alcohol fuel programs sketched out above are the most advanced, other countries are exploring the potential. Some are looking at agricultural by-products while others are considering the direct conversion of farm commodities into alcohol. Kenya is building an alcohol distillery that will use the molasses by-product of its sugar mills. Designed to use 180,000 tons of molasses a year, it will produce ethanol for blending with gasoline in Nairobi.[20]

The Sudan is also considering molasses-fed distilleries. The production of sugar from the vast new acreage of sugarcane to be planted in the Kenana Project between the White and Blue Niles will generate a large quantity of molasses. With no nearby market for it and with the nearest port 1,600 kilometers away, the conversion of molasses into liquid fuel for local use solves simultaneously the transport problems associated with the export of molasses and the movement of imported liquid fuels to the project area.[21]

Thailand, on the other hand, is interested in an agricultural fuel industry partly as a way to stabilize the prices of its agricultural commodities. It is seeking bids for the construction of distilleries that could be adapted to whatever crop might be in greatest surplus—cassava, maize, rice, sugarcane, or molasses. And in the Philippines, the government has undertaken a crash program to produce alcohol fuel from sugarcane. The production of "alcogas" (gasohol) was originally due to begin in 1982, but the government recently stepped up the program, setting an alcohol production goal for 1981 of some 5.8 million gallons of oil equivalent, and doubling the 1989 goal to an estimated 244 million gallons of oil equivalent. For the time being the alcohol will be derived largely from cane, although the government is also looking into the potential of using cassava and sweet potatoes.[22]

Interest in alcohol fuel is also strong in other sugar-surplus, oil-deficit countries of the Third World, where sugar prices have fluctuated while oil import bills have climbed. The balance-of-payment gains from the conversion of sugar into alcohol are obvious to economic policymakers. The Dominican Republic, Guyana, and Jamaica have each initiated feasibility studies of alcohol fuel production. A construction firm based in White Plains, New York, that builds alcohol distilleries reports that it now receives some 30 inquiries per week, mostly from sugarcane-producing countries, compared with perhaps one per week five years ago.[23]

Impact on Food Supplies

The numerous national programs to divert agricultural resources to the production of fuel crops come at a time when efforts to expand world food output are losing momentum. Between 1950 and 1971, per capita grain production worldwide increased by some 30 percent, leading to a substantial improvement in nutrition not only in industrial countries but in much of the Third World as well. Since 1971, how-

A tank car being filled with alcohol made from corn for gasohol at a plant in Decatur, Illinois.

DOE

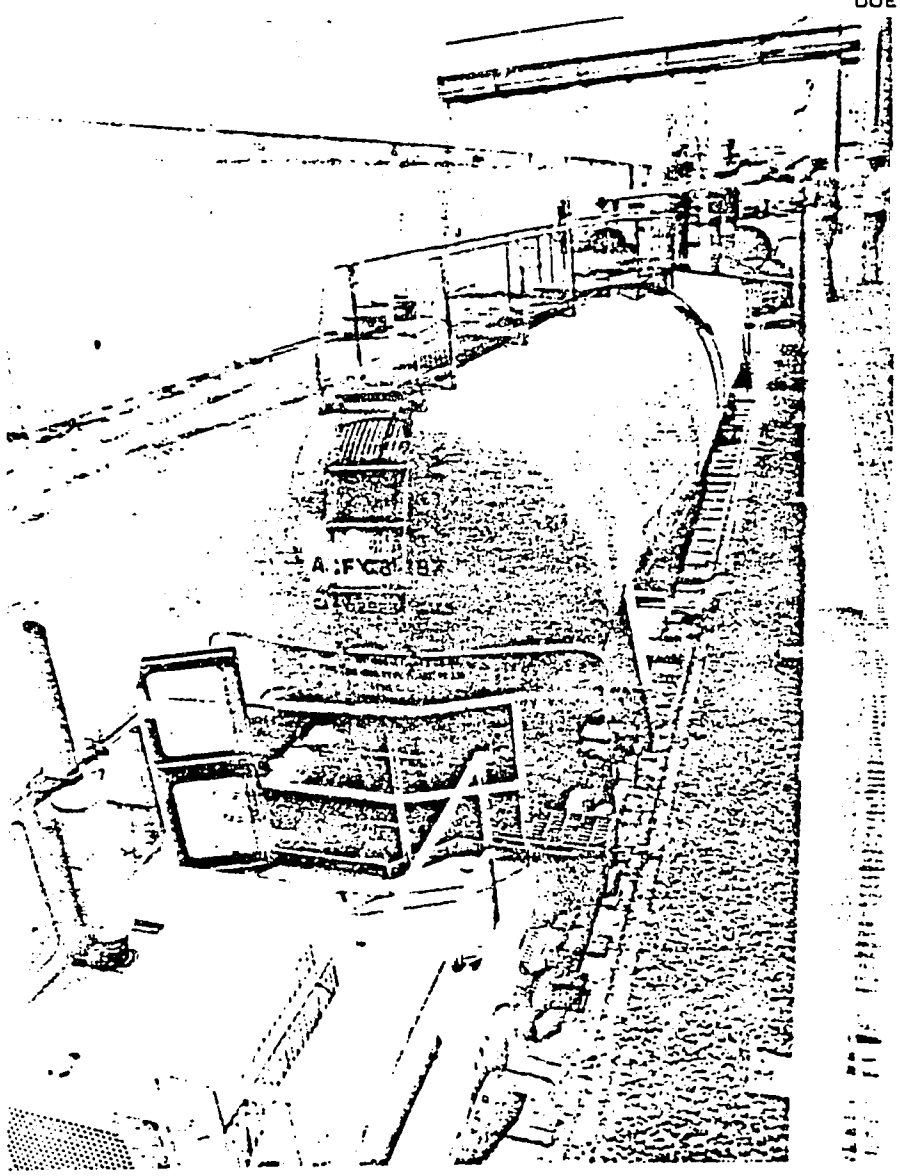


Table 1

ANNUAL PER CAPITA GRAIN AND CROPLAND REQUIREMENTS FOR FOOD AND FOR AUTOMOTIVE FUEL

	Grain	Cropland*
	(pounds)	*(acres)*
Subsistence Diet	400	.2
Affluent Diet	1,600	.9
Typical European Automobile** (7,000 miles/yr. at 25 mpg)	6,200	3.3
Typical U.S. Automobile** (10,000 miles/yr. at 15 mpg)	14,600	7.8

*Based on average world grain yields in 1978, according to the U.S. Department of Agriculture.

**Fuel use converted at 380 liters of alcohol per metric ton of grain.

SOURCE: Worldwatch Institute.

ever, growth in world food output has slowed, scarcely keeping pace with population growth. The failure of world grain output to match the increase in both population and incomes led to rising food prices during the seventies.[24]

Population and Supply

World demand for grain has been expanding by some 30 million tons per year over the past decade. Of this total, the bulk is needed to feed the increased number of humans, leaving little to upgrade diets. While world population growth has slowed, the absolute year-to-year increase remains at 70 million. In effect, the gradual decline in the rate of population growth has been offset by the increase in the size of the population base.[25]

Although population growth has dominated the growth in world food demand, rising incomes have also contributed to the increase, particularly in areas where consumption of livestock products, and the grain to produce them, has been rising rapidly. Prominent among these are a few industrial countries, such as Japan and the USSR, where meat consumption has until recently been relatively low, and the oil-exporting countries, where incomes are rising at an unprecedented rate.

On the supply side, growth in the world cropland base has slowed markedly since mid-century, expanding only one-fifth as fast as population. Other prominent reasons for the slowing growth in world food output are the continuing conversion of prime cropland to nonfarm uses, the excessive erosion of soil on at least one-fifth of the world's cropland base, the rising cost of energy for farmers, and the diminishing returns on additional applications of fertilizer in agriculturally advanced countries.[26]

All the forces that contributed to the loss of momentum on the food front during the seventies seem certain to intensify in the eighties. Even without the competition from energy crops, the world will be hard pressed to avoid a decline in per capita food production during the decade if the projected increases in population materialize. It is against this backdrop that the emergence of national energy crops initiatives must be evaluated.

Food versus Fuel

The potential claim of automobiles on future food-producing resources can best be illustrated by comparing the area of cropland required to feed a person with that needed to run an automobile on ethanol. Per capita grain consumption in developing countries averages roughly 400 pounds annually, or just over a pound per day. In the most affluent countries, where diets are rich in livestock products, each person annually consumes an average of 1,600 pounds of grain, including the amount eaten directly in cereal products and that consumed indirectly in the form of meat, milk, and eggs.[27] At average yields of grain, satisfying the annual food needs of a typical consumer in the Third World requires roughly one-quarter of an acre of cropland, whereas the more affluent consumer requires nearly an acre. (See Table 1.)

An automobile run on ethanol requires far more grain than a person does. A typical American car fueled by ethanol would require the processing of over seven tons of grain per year. In Western Europe, where cars are more fuel-efficient and are driven less, the typical automobile could be run on a little over three tons of grain per year. These numbers are in a sense hypothetical because, except for Brazil, no country has yet proposed running automobiles exclusively on alcohol. As for gasohol, fueling the typical U.S. car would require 1,460 pounds of grain in order to provide a 10 percent mix of ethanol with gasoline.

The social and political ramifications of a massive production of energy crops will probably surface first in Brazil, the only country that is committed to running its entire fleet of cars on alcohol. When President Figueiredo signed a protocol in September 1979 with the National Automakers Association confirming the intention of producing 250,000 automobiles in 1980 that would run entirely on alcohol, he was in effect claiming some 200,000 hectares of cropland for sugarcane. Government plans to produce 10.7 billion liters of alcohol by 1985 will require nearly three million hectares of sugarcane, the equivalent of 10 percent of Brazil's cropland. If the far more bullish projections of the alcohol fuel industry materialize, production will reach 20 billion liters and the area planted to sugarcane for fuel will approach one-fifth of the country's cropland.[28]

Brazil has one of the world's most widely skewed income distribution patterns, with a ratio of 36 to 1 between the average income of the richest one-fifth of its population and that of the poorest one-fifth. Evidence of malnutrition has been found in the country's high infant mortality rate and in the fact that less than half the children

Table 2

THE CHANGING PATTERN OF WORLD GRAIN TRADE*

Region	1934-38	1948-52	1960	1970	1978
		(million metric tons)			
North America	+ 5	+23	+39	+56	+104
Latin America	+ 9	+ 1	0	+ 4	0
Western Europe	-24	-22	-25	-30	- 21
Eastern Europe & USSR	+ 5	0	0	0	- 27
Africa	+ 1	0	- 2	- 5	- 12
Asia	+ 2	- 6	-17	-37	- 53
Australia & N. Zeal.	+ 3	+ 3	+ 6	+12	+ 14

*Plus sign indicates net exports; minus sign, net imports.

SOURCE: Food and Agriculture Organization, U.S. Department of Agriculture, and author's estimates.

under the age of 18 in 1975 had reached the normal weight for their age.[29]

The decision to turn to energy crops to fuel the country's rapidly growing fleet of automobiles is certain to drive food prices upward, thus leading to more severe malnutrition among the poor. In effect, the more affluent one-fifth of the population who own most of the automobiles will dramatically increase their individual claims on cropland from roughly one to at least three acres, further squeezing the millions who are at the low end of the Brazilian economic ladder.

Despite its vast land resources, Brazil is a chronically grain-deficit country, drawing on grain imported from abroad. Brazilian officials claim, however, that the production of energy crops will be in addition to rather than in competition with that of food crops. Yet energy crops compete not only for land but also for agricultural investment capital, water, fertilizer, farm management skills, farm-to-market roads, agricultural credit, and technical advisory services. In the absence of a planned economy where all agricultural inputs are carefully controlled and clearly tagged for the production of either food or energy, it would seem to be impossible to launch a major energy crops program without siphoning resources away from food production. The assumption that energy crops will not compete with food crops may be both naive and politically risky. The upward pressure on food prices that will be generated by the rapid expansion of energy crop production could put a severe strain on the Brazilian social fabric and political system.

The immediate consequences of the Brazilian energy crops program may be more internal than external, but the more recently launched effort in the United States has broader ramifications. If U.S. cropland is shifted to energy crops to fuel automobiles on a massive scale, it will be at the expense of our exportable surplus of grain. Over the past generation, the entire world has come to depend heavily on North American grain exports, with just over four-fifths of the total coming from the United States. (See Table 2.)

All but a handful of countries now import grain, most of it from North America. Since World War II, scores of countries have become food importers; yet not one new country has emerged as a significant cereal exporter during this period. Close to a dozen countries —including Algeria, Belgium, Japan, Lebanon, Libya, Senegal, Singapore, Switzerland, and Venezuela—now import more than half their total grain supplies.[30]

The cereals exported from North America—enough to feed 500 million people at Third World consumption levels—consist of large quantities of both food and feed grains, principally wheat and corn. And as more and more alcohol fuel distilleries are built in the United States in order to meet the official goal of producing two billion gallons of ethanol by the mid-eighties, the exportable surplus of grain will be reduced accordingly.

Making the Choice

Turning to energy crops as a source of automotive fuel opens a new chapter in the history of human efforts to achieve an adequate food supply. For the first time since agriculture began, the world is faced with a potentially massive diversion of agricultural resources to the production of nonfood crops. Unfortunately, this is beginning to happen at a time when efforts to expand world food output are losing momentum, when food prices are rising, and when malnutrition is increasing.

Whether the use of cropland to produce fuel for automobiles can be justified is a complex issue, one that political leaders will be wrestling with for years to come. Of the many considerations, the most critical one may be the difference between the perceived national interest in energy crops of food-surplus countries and that of food-deficit countries.

The attractions of alcohol fuel are clear. For countries buffeted by soaring oil prices and possible supply disruptions, the prospect of an easily available substitute for some of the imported oil is an inviting one. Although the world's oil reserves are concentrated in a handful of countries, the potential for producing energy crops is as widely diffused as agriculture itself.

There are also some solid environmental reasons to support alcohol fuel: it is clean-burning when used alone and when mixed with gasoline, it can substitute for lead as an octane booster. In contrast to the burning of petroleum, liquefied coal, or other automotive fuel of fossil origin, alcohol produced from plant materials does not increase the amount of carbon dioxide in the atmosphere, unless of course it leads to an overall reduction in the plant material in the world. In addition, alcohol is a renewable resource, a potentially important component in any effort to create a sustainable economy.

Economically, the move toward alcohol fuel is often justified by the additional employment it would create. Energy crop production and alcohol distillation are far more labor-intensive than are oil production and refining. And because distilleries are dispersed throughout the countryside, close to their feedstock supplies, they generate industrial as well as on-farm employment in rural areas where unemployment is usually highest. Jobs created in the countryside of the Third World can also help slow the migration to the mushrooming squatter settlements that surround so many cities.

The attractions of agriculturally derived alcohol fuel must be set against its potential impact on world food prices. By far the most serious environmental impact of energy crops will be the additional pressures they put on cropland. The doubling of world food output over the past generation has led to the adoption of cropping practices that are resulting in excessive soil erosion. At least one-fifth of the world's cropland is now losing topsoil at a rate that is undermining its productivity. With the demand for food projected to double again over the next generation, it will be difficult to lighten the demands on soils and to arrest their long-term deterioration. If, in addition, vast areas are planted to energy crops, the problem will become even more unmanageable.

As the number of distilleries multiplies, the production of energy crops will expand until an economic equilibrium is reached between the price of agricultural commodities used as distillery feedstock and those used for food or feed. In the absence of any governmental limitations on the conversion of agricultural commodities into fuel, the price of oil could eventually set the price of food.

The expanding production of fuel crops will underline the vast disparities in income within and among societies as perhaps nothing else has ever done. Until recently, the average per capita claim on the earth's food-producing resources has not usually varied from the richest to the poorest countries by more than a factor of five to one. With the advent of energy crops, however, the ratio could increase dramatically. In effect, the use of energy crops to fuel automobiles permits the world's affluent to expand greatly their claim on the world's cropland area.

The question is not whether there should be an alcohol fuel industry. Clearly, there are many possibilities for converting agricultural wastes and other sources of plant materials into automotive fuels that need to be urgently pursued. Over the longer term, a carefully designed alcohol fuel program based on forest products and cellulosic materials of agricultural origin could become an important source of fuel, one that would not compete with food production. Liquid fuel from plants, whether in the form of alcohol or as direct hydrocarbon extracts, is an energy source that needs to be aggressively exploited everywhere. At issue is whether governments can encourage the production of alcohol fuel without inadvertently launching an industry that competes directly with food production.

If the potentially adverse effects of

Gasohol, a 10 percent alcohol-with-gasoline mixture, has so far been introduced in only a few places in the United States.

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current programs to produce fuel from crops are to be minimized, several steps must be taken immediately. The governments launching these programs need to warn food-deficit countries of the potential reduction in exportable food surpluses so that they can adjust their agricultural and population policies accordingly. Secondly, the move toward energy crops reinforces the need for an internationally coor linated effort to arrest the excessive erosion of topsoil. Without such an initiative, the widespread planting of energy crops will accelerate the deterioration of the world's cropland base. Where agricultural fuel programs are launched, priority in the use of fuel should be given to tractors and other farm uses over automobiles. And finally, a global food-price monitoring system that would be sensitive to the impact of alcohol fuel programs is needed. Such a system is essential if political leaders are to assess the worldwide impact of national energy crops initiatives on food prices.

Within the food-exporting countries, the short-run attractions of converting exportable food surpluses into alcohol fuel are undeniable. Whether the longer term political effects will be as attractive is less clear. In a world that no longer has any excess food production capacity, the decision to channel foodstuffs into the production of automotive fuel will inevitably drive food prices upward. For the world's affluent, such rises in food prices may lead to belt-tightening; but for the several hundred million who are already spending most of their meager incomes on food, continually rising food prices will further narrow the thin margin of survival.

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THE Conversion OF Tropical Forests

BY NORMAN MYERS

THE TROPICAL MOIST FOREST BIOME (ecological community) is biologically the richest and least well-known portion of the earth's surface. In this biome are to be found several million kinds of organisms, of which no more than half a million have even been given a Latin name. Many of the known and unknown species of organisms in the tropics offer significant potential for utilization by man, and all are of intrinsic scientific interest. A number of tropical plants, including rubber and oil palm, have been brought into wide-scale cultivation within the past century. Many more should be investigated as to their useful properties.[1]

Not only is the tropical moist forest (TMF) biome large and spread across three tropical regions, but it is much more differentiated than many observers suppose.[2] It is divided among some 70 countries, of which almost 40 contain tracts of TMF that are appreciable in size or significant for their ecological and biotic values. However, more than four-fifths of the biome occurs in only nine countries—Bolivia, Brazil, Colombia, Peru, and Venezuela in Latin America; Indonesia and Malaysia in Southeast Asia; and Gabon and Zaire in Africa.

Biotic Diversity

The TMF biome is, biologically and ecologically, the most complex and diverse on earth. There is marked diversity of species, especially of trees, woody climbers, and epiphytes. This characteristic is most notable in wetter areas with high atmospheric humidity. The complexity is both dynamic (with an exceptional degree of biotic and physiobiotic interactions) and stable (able to maintain itself for long periods if not indefinitely).

It is a mistake to suppose, however, that this diversity and stability are interrelated in a simple and positive fashion. Indeed, recent theoretical and empirical research suggests that "communities with a rich array of species and complex web interactions (the tropical rainforest being the paradigm) are likely to be more fragile than relatively simple and robust temperate ecosystems."[3]

The dynamic relationship between complexity and stability is particularly significant since it appears to depend on an important provision,

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Fertilizing young oil palms in the main nursery before later replanting in cleared jungle in the Jengka Triangle in the State of Pahang, West Malaysia.

namely that external forces impinging on the system should not exceed certain threshold values; otherwise distinct and enduring changes may arise. Human intervention—which can be massive both in terms of immediate impact and long-run duration—can readily exceed the capacity of TMF regulatory processes to maintain the system.

TMF species are unusually susceptible to extinction because many have highly specialized ecological requirements, many exist at low densities, many are confined to localized distributions. These three attributes alone mean that these species are highly vulnerable to sudden elimination when a tract of forest is subjected to the more disruptive forms of conversion; a tract of forest does not have to be entirely cleared for a number of its resident species to become extinct.

Elimination of a substantial proportion of the planetary spectrum of species will mean a gross reduction of life's diversity on earth; it will entail a permanent shift in the course of evolution, and an irreversible loss of economic opportunity as well.

Primary and Secondary Forests

Primary forest is forest that has been undisturbed for a long time—at least for decades and sometimes for centuries. Primary forest often consists of forest that has worked its way through successional stages of development as a young forest and is now approaching or has attained a state of maturity, often considered to be a state of ultimate diversity and complexity. Such a formation has been termed by some researchers a climax forest—one representing a vegetation type in dynamic equilibrium with the climate in which it occurs.

The make-up of plant species in a secondary forest is fundamentally different from that in a primary forest. In addition, the structure and functioning of the community are different, and the ecosystem is less diverse. After a tropical primary forest has been cleared, and the plant life left to regrow, there is a rapid accumulation of new biomass until it peaks at roughly 15 years—after which only the nature of the plant life changes.[4] Through a process that occurs slowly, or extremely slowly, pioneer species and low-ground vegetation disappear, their detritus providing nutrients for larger and longer-lived trees. Eventually the secondary forest develops steadily toward a formation akin to that of primary forest; and in time, provided all the necessary complex of factors is available, primary forest will reestablish itself.

But secondary forests tend to persist for long periods. In areas of disturbed rainforest in northeastern Australia, 50 years' regeneration has produced forests that are floristically similar to nearby undisturbed forest but that are still structurally dissimilar.[5] Around Angkor in Kampuchea (Cambodia) the forest of large areas that were reputedly cleared 600 years ago does not yet fully resemble surrounding patches of undisturbed primary

forest. Indeed, it is thought that certain lowland rainforest ecosystems after being grossly disrupted or destroyed may need a successional process of as much as 1,000 years before a final-form primary forest ecosystem is reestablished.[6] Although natural forces, such as typhoons, can also damage primary forests, generally speaking, it is human influence that causes secondary forests to appear in the contemporary TMF biome.

Causes of Conversion

By far the most important factor in conversion of tropical moist forests appears to be the forest farmer, whether using traditional shifting cultivation, smallholder agriculture, or some type of squatter colonization. It has been estimated that, in the mid-1970s, these forest farmers totaled at least 140 million, occupying some 2 million km^2 (or over one-fifth) of the TMF biome.[7]

There is reason to believe that the estimation of 140 million forest farmers represents a minimum number. At an average size of seven persons per family (a roughly acceptable figure for Central America, Colombia, Indonesia, the Philippines, and Thailand), this means there are some 20 million families. If each family clears one additional hectare each year, as seems to be minimal practice, the forest farmers are clearing some 200,000 km^2 of forest each year. Although many of these farmers exploit secondary forests and although in certain sectors of primary forest (for example, in Central Africa) population densities are still low enough to permit the forest to be used while sustaining its quality and composition with prospect of eventual regeneration of primary vegetation, it is not unrealistic to suppose that forest farmers are converting at least 100,000 km^2 of primary forest to permanent cultivation each year. Thus forest farming could well be accounting for the loss of over 1 percent of the TMF biome each year.

Cattle raising also plays a substantial role in the conversion of tropical moist forests, especially in Latin America. Between 1950 and 1975, the area of man-established pasture in Central America more than doubled, almost entirely at the expense of primary moist forests. In Brazilian Amazonia cattle raising is now the dominant cause of forest conversion. Although many cattle ranches in Amazonia become unprofitable within less than 10 years because the productivity of the newly created grasslands declines, a rancher can generally obtain another patch of forest to clear, thus practicing a new and broad-scale variation of shifting agriculture. As long as beef continues to bring high prices in the developed world, cattle raising is likely to be an increasingly important cause of destruction of primary TMF.

One of the main reasons for the growing exploitation of tropical moist forests is the desire for more wood. This is true not only of the tropical countries but of communities in the developed world that increasingly look to TMF to meet their consumption demands.[8] Although the tropical moist forests contain about as much wood as their temperate counterparts, TMF now supply little more than one-tenth of total wood used worldwide as solid wood and as paper pulp.

The Timber Trade

During the last three decades, there has been a rapidly growing demand on the part of developed nations for tropical timber, especially for hardwoods, the kind of timber that makes up over 90 percent of TMF (Table 1). Hardwood supplies many needs: housing construction; finished products such as furniture; and wood-based panels such as plywood, veneer, particleboard, and fiberboard. Of the world's hardwood forests, the great bulk are located in the tropics. Hardwood forests of temperate zones have been steadily depleted or are coming under greater protection in order to meet environmental interests and, as a result, exploitation pressure is increasingly directed toward TMF.

After the economies of the developed world recovered from World War II, they began to import tropical hardwood timber, some 4.2 million m^3 in 1950 (Table 1). Within three decades, the volume has grown by almost 1,500 percent, and it is projected to expand by more than half as much again, to 95,000,000 m^3 by the year 2000. True, tropical regions use a lot of hardwood timber themselves, but the amount has little more than doubled since 1950, whereas the developed world's imports have increased 15 times, and the total has recently surpassed consumption by all tropical countries combined.

The largest single consumer of tropical hardwoods is Japan, now accounting for over half of the developed nations' imports (Table 1). Between 1950 and 1973, Japan's consumption of tropical hardwoods increased 19 times, with three-quarters of the aggregate supply deriving from Southeast Asia. Among all Japan's imports, wood now ranks as a strong second to oil; the country depends on overseas sources for around two-thirds of its wood, a proportion that could rise as high as four-fifths by 1985 (some of the imports stem from North America, but hardwood imports almost entirely derive from the tropics).[9] Hitherto Japan has looked mainly to Southeast Asia for its hardwood needs, but it is increasingly directing attention toward Latin America and West Africa.

Table 1

CONSUMPTION OF TROPICAL HARDWOOD TIMBER: PAST, PRESENT, AND PROJECTED (MILLION m^3)

COUNTRY/REGION	1950	1973	1980	1990	2000
Japan	1.5	28.9	35	38	48
United States	0.8	7.2	10	15	20
Europe	1.9	17.2	21	27	35
Total three importing regions	4.2	53.5	66	80	95
Tropical producing regions	21.0	46.5	66	117	185
Rest of world	1.0	9.0	13	18	23
Total	26.2	108.8	145	215	303

SOURCE: FAO, Forest Resources in Asia and Far East, 1976; and S. L. Pringle, "Tropical Moist Forests in World Demand, Supply and Trade," Unasylva 28 (1976).

Table 2

SUPPLY OF TROPICAL HARDWOOD TIMBER: ACTUAL AND PROJECTED (MILLION m^3)

REGION	1950 PRODUCTION	1950 EXPORT (%)*	1973 PRODUCTION	1973 EXPORT (%)	1980 PRODUCTION	1980 EXPORT (%)	1990 PRODUCTION	1990 EXPORT (%)	2000 PRODUCTION	2000 EXPORT (%)
Tropical Africa	4.7	1.5 (32)	16.5	11 (67)	20	12 (60)	25	9 (36)	35	10 (29)
Latin America	15.5	0.8 (5)	20	3 (15)	32	4 (13)	60	7 (12)	118	28 (24)
Southern and Southeast Asia	14.3	2 (14)	72.5	48.5 (67)	93	65 (70)	130	82 (63)	150	80 (53)
Total	34.5	4.3 (13)	109	62.5 (57)	145	81 (56)	215	98 (46)	303	118 (39)

*Figures in parentheses are percentage of production given to export.

NOTE: As tropical developing countries themselves start to consume more of their hardwood output, there will be (except in the eventual case of Latin America) a smaller share available for export to developed countries. At the same time, developed countries' demand will steadily expand. So there will be compounded pressure to exploit tropical hardwood forests.

SOURCES: S. L. Pringle, "Tropical Moist Forests in World Demand, Supply and Trade," Unasylva 28 (1976); and other FAO documents.

The United States is the second largest consumer of tropical hardwoods. U.S. demand has been growing at a rate far above the country's growth rates for population and GNP. This has been partly caused by rapidly rising costs of high-quality hardwoods from within the United States, following increased interest in the country's hardwood forests for their esthetic and recreational values. A more important reason is that plywood panelling can be obtained relatively cheaply from Southeast and East Asia; over four-fifths of U.S. imports of tropical hardwoods come in the form of plywood and veneer via Japan—the so-called Philippine mahogany that originates in Southeast Asia. Between 1950 and 1973, U.S. imports of tropical hardwoods increased 9 times (until the country was accounting for about 70 percent of all tropical plywood and veneer entering world trade), and by the year 2000 they are projected to double again.

The nations of Western Europe account for about one-third of the developed world's imports of tropical hardwoods, an amount that is projected to increase by about 75 percent by the year 2000. Most of the timber derives from West and Central Africa, though within the last few years there has been a marked expansion in hardwood imports originating from Southeast Asia.

By far the major source of tropical hardwoods to date has been Southeast Asia (Table 2). Between 1950 and 1973, the region increased its exports 24 times, until it was accounting for three-quarters of international trade in tropical hardwoods. Latin America, with around 3 times as many hardwood stocks as Southeast Asia, currently produces only 10 percent of the world's hardwood timber and exports very little, due to the remote location of many of its hardwood forests. West and Central Africa export only about one-third as much as Southeast Asia. Plainly, however, the progressive depletion of Southeast Asia's forests will cause much greater exploitation pressure to be directed toward the two TMF regions that have hitherto supplied little to international hardwood trade, namely, Amazonia and Central Africa. As harvesting technology allows loggers to extract timber from localities that are currently considered inaccessible because of such factors as difficult terrain or remoteness, and as processing technology enables more heterogeneous types of hardwoods to become acceptable on commercial markets, both Amazonia and Central Africa can be expected to increase their share of the hardwood timber trade.

Paper Pulp

While global consumption of hardwood products is expected to continue to expand, it is paper products for which the greatest growth in demand is projected. TMF contain relatively few stocks of the conventional source of paper pulp, i.e., softwoods. But the international paper trade now expects to depend on TMF for much of its raw materials, as a consequence of recent changes in forestry technology. Until the mid-1970s, it was thought that TMF, with their multiplicity of hardwood species, could not readily be pulped after the manner of softwoods. But new production processes now allow wood chips from some 100 selected TMF tree species to be simultaneously converted into pulp.[10] TMF, comprising some 55 percent of the world's forests, currently produce only 7 percent of the world's paper and paperboard—a percentage that could shortly start to grow rapidly.

During the period 1950-1970 world output of paper products increased from 40 to 130 million tons for a growth rate twice that of population. If long-term trends continue, world demand could rise from its present level of around 180 million tons per year to 400 million tons by the year 2000, and to twice as much again after only a further two decades.[11]

The developed world now uses almost 160 million tons of pulp a year, the developing world little over 20 million. An average developed world's citizen consumes an annual amount of over 155 kg of paper and paperboard (in the United States, 325 kg), while a developing world world's citizen is unlikely to use more than 5 kg. (Many a citizen of Indonesia and Nigeria may not even account for 1 kg, roughly half of one copy of the Sunday edition of the *New York Times*.) If consumption continues to grow as in recent years, the developing world is projected to expand its consumption roughly 3 times, as compared with a 2¼-times increase on the part of the developed world; thus by far the largest share of

total consumption will remain with the developed world.

Whereas many nations of North America and Western Europe are self-sufficient for paper pulp or even produce a surplus, Japan is heavily dependent on foreign sources, almost half of its pulpwood now coming from overseas. Following recent increases in prices of U.S. softwood chips, Japan is turning to Southeast Asia and tropical America for hardwood chips, which now supply over half of its pulpwood-chip needs.[12]

Even though their consumption rates are presently very low, developing countries are strongly motivated to develop sources of paper pulp. They currently import the great bulk of their supplies, at a 1975 cost of $2 billion—worth almost two-thirds of developing countries' exports of tropical timber. To give an idea of low-level demand in developing countries, and of the amount by which it could expand, total newsprint consumption in 14 Asian countries, including all the most populous ones except China, now totals around 600,000 tons per year, or less than Canada's.

Not only does demand for paper increase with growing human numbers, it expands much more as a consequence of growing human aspirations. In particular, the spread of literacy serves as a powerful stimulus to demand—and in many developing countries, lack of paper is causing serious setbacks to education and communications. Within another decade, there will be a further 150 million consumers of paper in developing countries; by the year 2000, Southeast Asia is expected to need five times as much paper as in 1974. Indonesia, after paying out $92 million for pulp imports to meet 85 percent of its needs in 1977, has a strong incentive to use its own forest resources as a pulp source.

Economic Value

Between 1954 and 1976, tropical wood exports increased in value from $272 million to $4.2 billion. This represents a growth rate far faster than that for global trade in all forest products. Tropical wood exports now amount to around 4 percent of the value of all the developing world's exports excluding petroleum, making it one of the five most important export earners among major commodities produced by the developing world. In fact, tropical wood is now one of the fastest growing exports of the developing world, earning about as much revenue as sugar, cotton, or copper.

Yet, substantial and expanding as these export earnings are, trade in tropical wood nevertheless amounts to only about 15 percent of global trade in forest products. The Congo and Finland have land areas and forest estates roughly the same size, yet in 1973 the value of Finland's forest exports was 60 times greater than the Congo's. The six main countries of the Amazon Basin, plus French Guiana, Guyana, and Suriname, possess 2.7 hectares (ha) of forest per person, compared with a world average of about 1 ha; yet they import more forest products by value than they export.

Ecological Impact

Due to the diversity of tree species in tropical forests, coupled with the reluctance of international timber markets to take more than a small proportion of wood types available, the commercial logger is inclined to harvest very selectively, taking a few choice specimens with disregard for the rest—a "creaming" operation. Of Amazonia's many thousands of tree species, only about 50 are widely exploited, even though as many as 400 have some commercial value. Africa exports only 35 principal species (albeit twice as many as in 1950), with 10 accounting for 70 percent of the total.[13] In Southeast Asia, loggers focus on less than 100 tree species, with exports consisting mainly of only a dozen or so.[14]

So when a patch of TMF is exploited, only a few trees, often less than 20 of 400 per ha, are taken. Yet the logging operation can leave many of the remaining trees damaged beyond recovery—far more than would be the case in a temperate-zone forest—because TMF trees are strongly linked together with vines, lianas, and other climbing plants, sometimes as many as 2,000 per ha and some of them 200 m long.[15] Commercial trees are often limited to the tallest, which, benefiting from the sunlight, develop crowns as widespread as 15 m. When one of these giants is felled, it is likely to break or pull down several

others with it. Furthermore, tropical trees are highly susceptible to attack by pathogens; as a result, a seemingly minor injury, such as a patch of bark torn off, can leave a tree vulnerable to irreparable damage. Logging roads and haulage tracks, sometimes averaging as much as 10 km for each km^2 of forest exploited, can, together with dumping zones and land for logs, account for 10 to 30 percent of the forest area.[16]

Repeated surveys in Southeast Asia reveal that the average logging operation leaves between one-third and two-thirds of residual trees damaged beyond recovery.[17] In addition, almost one-third of the ground may be left bare, in many instances with the soil impacted by the heavy machinery.[18] With greater care, the damage could be reduced by half. But less destructive exploitation would raise timber prices for the end-product consumer—something that the main markets (developed nations) are unlikely to accept on the grounds that it would be unduly inflationary.

Clearly, logging impact varies from area to area. In some places, the consequence is only light modification of the forest, while in other places it amounts to gross degradation. If the logging is highly selective, e.g., for mahogany, it is possible that the forest may never return to its original composition. Even if the logging is less selective, it will still take many more than a few years for natural regeneration to fill the gaps caused by the removal of timber trees.[19]

Wood Chips

Forestry technology has recently developed processing methods that enable tropical hardwoods to be pulped in a single mixture.[20] In Colombia, some 100 species are used in one operation, subsequently supplying 40 percent of the kraft and linerboard. In Papua, New Guinea, a joint hardwood chip mill, established in 1974, accepts over 200 species at once. Similar operations are under way in Brazil, Indonesia, Malaysia, the Philippines, and Thailand. Since the techniques cannot only be applied to sound trees of any sort, but can be used to salvage defective trees and dead standing timber, they can expand the yield of a hardwood forest by as much as an additional 300 percent of usable wood.[21]

Thus the extreme heterogeneity of TMF no longer presents a problem to the forest exploiter who seeks to manufacture wood pulp. This represents a welcome breakthough not only for Japan, with its large and growing demand for wood chips from overseas, but also is of potentially enormous benefit to tropical-forest countries themselves, with their fast growing need for wood pulp.

Furthermore, some observers look upon this "any-tree/all-tree" harvesting, also known as full-forest harvesting, as an innovation that could represent some sort of salvation for TMF, at least so far as certain forms of wood exploitation are concerned. By enabling intensified production of wood products in a few selected areas, it could relieve extensive harvesting of wood from large tracts of forests. Other observers are inclined to believe that it could amount to a two-edged sword. Under this technique, a patch of forest is not exploited selectively, on a sustained-yield basis; segments are exploited entirely, once and for all.

However, if a harvested forest is then replaced by a man-made forest, this intensive use both of the original forest and of the land on which it stood may help to confine timber harvesting to limited localities. Alternatively, full-forest harvesting can be conducted in scattered blocks, or in strips possibly up to 200 m wide (although no experimental studies in tropical forest management have shown 200 m to be the upper limit of clear-cut strips), whereupon the surrounding tracts of undisturbed forest will eventually enable the exploited zone to regenerate. But this sophisticated harvesting technique can work to ways: it can either hold out better prospects for many sectors of untouched forest, or it can presage total conversion for many sectors.

Plantations

In a few localities of the tropics, forest plantations are being established. These plantations now comprise around 85,000 km^2. Of this total, almost 40,000 km^2 are in Latin America (over half in Brazil), and the rest split between southern and Southeast Asia, and West and Central Africa.

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Seedlings to supply firewood being grown in the Kombissini nursery in Upper Volta.

To the extent that man-made forests supply the quantities and types of wood required by world markets, they reduce the pressure to exploit primary forests. So fast-growing are some plantation tree species that a 500-km² plantation can readily produce 1 million m³ of marketable timber per year, a volume that could be obtained only from 10 times as large an area of natural forest.[23] However, only 5,000 km² or so of additional plantations are established each year—only one-third as many as would be required to supply enough wood to relieve extreme exploitation pressures on TMF during the course of the next two decades.

In any case, tropical forest plantations are not without problems. They can prove costly to establish, $200 to $400 per ha. In common with many monoculture crops, they tend to attract diseases and pests that are numerous and varied. When plantation trees are harvested, they may take a large stock of nutrients with them, requiring the use of ever increasing amounts of fertilizer to maintain productivity.

The greatest expanse of tropical plantations, some 25,000 km², is in Brazil, one of the world's most impressive forestry accomplishments. Less than 1,000 km² are located in Amazonia, with the rest in southern Brazil, where broad-leaved species are grown on 13,000 km² and conifers on 10,000 km².

In 1975 Brazil consumed 1.9 million tons of paper, an amount that is expected to reach 4 million tons by 1985. Although Brazil is now among the world's 10 leading pulp producers, it imported 700,000 tons of pulp and paper in 1974, worth $349 million.[25] As a result of its plantation program, established in the mid-1960s, Brazil aims to produce enough pulp to meet its own needs by the early 1980s, and by the year 2000, Brazil plans to have an annual surplus of 20 million tons of pulp for export to other countries of Latin America (worth at present prices, $5.5 billion).[26]

This long-term program will require an additional 40,000 km² of plantations. During the 1970s, the average price of land for reforestation in some of Brazil's heavily populated southern areas has increased 11 times, so there is strong incentive to look for opportunity elsewhere—notably in Amazonia, where there are scheduled to be 10,000 km² of plantations by 1985. Nonetheless, even if all additional plantations of the next two decades were to be located in Amazonia, they would not have to affect more than 1.5 percent of the present forest expanse.

Obstacles

From the standpoint of safeguarding primary TMF, the most appropriate strategy is to establish plantations in forest territories that have already been exploited and have become poor-quality secondary forest, degraded grasslands, or areas that have been overburdened by forest farmers. There are 440,000 km² of such misused lands in Indonesia alone—an area larger than the country's designated protected forests. A number of pioneer tree species can be made to grow satisfactorily in such areas.

Regrettably, an outcome of this sort is generally precluded by at least two factors. First, a plantation entrepreneur seeks to locate his concession within an extensive tract of primary forest, so that he can exploit the hardwood timber to capitalize his plantation. Secondly, already cleared forest-lands are generally occupied by settlements of one sort or another, and it is politically difficult to uproot these in order to plant trees.

A further problem arises, one that could severely reduce the expanse of plantations to be established anywhere in TMF countries. This concerns the scale of investment that will have to be made available for plantations (plus associated processing industries) if they are to make a sizable contribution to tropical timber supplies during the foreseeable future. Food and Agricultural Organization and World Bank estimates run as high as $3 billion per year over the next two decades.

In the face of investment requirements of this magnitude, TMF countries are increasingly looking toward the foreign investor: half of Latin America's total sales of paper and paperboard have recently been accounted for by affiliates of U.S. timber corporations;[27] and Brazil has just reached agreement with 11 Japanese companies for a $1 billion, 4,000-km² pulp project. Yet foreign investors are not moving into the field of tropical plantations as fast they might. They are not sufficiently assured concerning security of prices for their products, or security of tenure for their holdings.

Each inflationary upheaval in world currency systems, and each nationalization of a foreign enterprise in a tropical country, defers the day when enough plantations will be established to relieve the more excessive timber exploitation pressures on TMF. Considering that plantations require a lead time of at least 10 years before they start to produce wood in bulk, stabilizing a favorable politico-economic environment for the foreign entrepreneur is an urgent requirement.

NOTES

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2. Despite the exceptional ecological and economic value of the tropical moist forest biome there is no standard and objective definition of "tropical moist forests." The definition of tropical moist forests (TMF) I have used here is as follows: "Evergreen or partly evergreen forests, in areas receiving not less than 100 mm of precipitation in any month for 2 out of 3 years, with mean annual temperature of 24+ °C and essentially frost-free; in these forests some trees may be deciduous; the forests usually occur at altitudes below 1,300 m (though often in Amazonia up to 1,800 m and generally in Southeast Asia up to only 750 m); and, in mature examples of these forests, there are several more or less distinctive strata."

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Trucks remove timber from jungle in the State of Pahang, West Malaysia.

World Bank/Mary M. Hill

ASPECTS OF LAND AND WATER MANAGEMENT

1. "Using Natural Resources as a Planning Guide"
2. "The Ganges Water Machine"
3. "Land Use for Agricultural Production: Agricultural Land Use and Soil Erosion"
4. "Alternatives to Pesticides in the Southeastern United States"
5. "Integrated Pest Management in China"

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Chapter III
Using Natural Resources as a Planning Guide

Rural areas are fortunate in still being able to make planning choices based on existing natural resources. Although it would appear self-evident that choices must be based on the land in rural areas, the method of land-use planning that starts with the natural resource base is sometimes overlooked by planners trained to deal with urban situations where the possibility of making such choices has long since disappeared. In recent years, increasing numbers of rural areas have recognized their special opportunities and have developed planning methods which take natural resources as their starting point.

Planning based on the natural resource base is motivated not only by the desire to conserve and protect desirable natural features (although this is of course an important point), but also by a belief that development of any kind—roads, residences and shopping centers—can best be located, with less present expense and fewer future problems, if based on an understanding of natural constraints. The natural environment can structure the optimum location of development and save the community problems in the future—problems with provision of water, for example, or with erosion, settling, and sedimentation. Once the natural characteristics of the land are mapped and classified, a clear physical structure which constrains or permits future growth often becomes apparent.

Preparing the inventory and classification of natural resources is an important part of rural environmental planning. Out of the variety of existing characteristics that can be looked

at, the planner selects for analysis those which will have the most important effects on future development. It is clear that topography, soils and water are important. Topography dictates the location of roads and houses; clearing steep slopes for building is not only expensive but may create future problems affecting the stability of larger land areas. Soils have important characteristics which must be respected: permeability relates to the location of septic systems; bearing capacity affects the costs of new housing, and preserving agricultural potential may be necessary for the economic health of the community. Though it is hardly necessary to point out the value of a pure water supply, the relationships between the supply of water and other characteristics of the natural resource base are not always obvious. A natural resource inventory can help to point out important relationships between the various natural and man-made systems. Geology, vegetation, wildlife, and unique natural or man-made features all play different parts in maintaining the desired quality and unique identity of a given region.

This chapter provides a guide to some of the techniques involved in preparing the inventory of existing conditions, offers some aids to the planner or citizens making the inventories, and suggests some of the characteristics of existing resources which must be examined and interpreted.

Maps

A useful resource inventory is compiled by describing and mapping each set of natural features and existing land uses individually: topography, hydrology, soils, geology, vegetation, and wildlife are suggested as basic categories for maps. Other natural resource categories, however, may be selected. The primary sources of information will be existing maps, verified by field checking where possible, supplemented by reports, studies, and surveys.

It is important to keep in mind that along with maps and other printed documents, there is no substitute for firsthand information: local specialists such as hydrologists and geologists at nearby universities are frequently the most expert sources of

information in a region. Not only will they be able to interpret configurations, statistics, and other data, but they will probably have recent information and field experience. Agencies working with maps should maintain close contact with those who compiled and published the maps. For example, any decisions based upon soil, geological, or topographic considerations should be made only after consultation with the regional offices of the Soil Conservation Service of the U.S. Department of Agriculture. Aside from their ability to interpret maps, they will have updates and amendments on hand.

Maps will be of little use unless they are able to be interpreted and evaluated easily. The identification of sub-areas for their intrinsic suitability for conservation or for future development might be the guiding principle in preparing a presentation. For each of the major data categories, factors related to *conservation* or to *development* should be selected and highlighted. For an initial planning effort a simple summary categorization of data will be helpful. For example, in presenting an interpretive map of slope conditions, "slopes greater than 25 percent—usually no development" may be represented by dark shading; "slopes from 15 to 25 percent—suited for development" and "slopes of 0 to 3 percent—acceptable for development if no ponding or erosion problems" should be shaded successively lighter. By such a presentation, major categories will be clear. What is important is to recognize that too much data may be as difficult to understand as too little. For purposes of clarity, or to highlight a variety of values, it may be useful to prepare more than one interpretive map for a given category. For example, a soils map may be prepared which highlights soils suitable for agriculture, and one which highlights soils suitable for construction.

Since each set of data (e.g., soils) should be recorded on its own map, it is essential to have a good base map, which acts as a reference point upon which subsequent maps are placed. Base maps should display all man-made features in the region: roads, political boundaries, and even individual structures, if the scale is small enough to permit it.

The base map should be of a convenient size for work in the field, and easily reproducible. It is important to keep it simple

and legible. Scale should relate to the capabilities of reproduction equipment readily available. If the map is to be reproduced in sections to be pasted together it should be divided in such a way as to make matching easy. Sections should also be divided in such a way as to be easily reproducible on available equipment. If maps are to produce maximum benefits, they should be readily available and relatively inexpensive.

It may be useful to have a base map prepared in two or even three different scales or sizes in order to meet all eventual demands. For all towns but those of very small size, it may be desirable to have a base map with sheets at a scale of 1" = 200" or less for central areas which are densely settled. For areas which are developed with a number of 50-foot lots, a scale of 300 to 600 feet to an inch is about the minimum for acceptable legibility. For a rural area which wishes to include a central village with extended environs on its base map, ability to measure within fractions of a mile is all that is needed. In this case 1,000 feet or a half mile to the inch will be appropriate. The final choice will depend on the size of the community and its particular needs. Combining maps of several scales for the preliminary survey may be the most workable procedure.

The U.S. Geological Survey (USGS) maps at a scale of either 1:24,000 1" = 2,000 feet (7½ minute) or 1:62,500 (15-minute) 1" = approximately 1 mile (the former being more accurate than the latter) are convenient and useful references. Land Use and Land Cover and Associated Maps are now being compiled by the USGS for the entire country.

In 1974 the National Cartographic Information Center (NCIC) was established by the USGS to provide information and assist data users in obtaining both general and special cartographic information. They are an excellent source of help.

Topography and Slope

Land use is determined, to a great degree, by elevation and slope. Historically, development progressed through lowlands, into valleys, and around hills and mountains. Although this general pattern still remains true, today there are far fewer

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restrictions on developing steep slopes and other areas once considered inaccessible or undesirable. For this reason, the shape of the terrain must be known if land use is to be properly planned. As elevation increases, so do the costs of roads, utilities, and maintenance services, such as snow removal. As the degree of slope increases, so does the difficulty of building and supporting structures.

The development of hillsides must be approached with care because such development can affect the equilibrium of a region or district wider than anticipated. Care must be exercised when tampering with the harmony of slope, soil, vegetation, drainage patterns, and geological foundation.

Bad planning can disturb soil stability, causing erosion and a resulting loss of slope; careless removal of vegetation from hillsides deprives the grade of the cemental network of plant roots, alters established drainage pathways, or eliminates a natural wind screen. Such a loss of protection permits rapid erosion, which adds silt and other sediment particles to downstream waterways and sullies immediate water quality. Spring thaws or strong rains on unstable slopes can produce mass movements, such as landslides, slumps, and flaws, particularly in steeply sloping areas.

By the removal of vegetation, hillside development also increases runoff that would ordinarily be retained and transpired by trees and other vegetation. The detrimental effects of hillside disturbance are increased by the addition of impervious surfaces, such as paving and buildings, further reducing groundwater percolation, thus adding to the amount of runoff, destruction of water quality, and potential for flooding.

Furthermore, disturbance of hillsides can destroy a community's aesthetic resources. A range of hills frequently marks a community's boundary and provides an attractive scenic setting for homes and buildings. Degradation of hillsides as a result of erosion and loss of vegetation deprives a community of its attractive and distinct setting and decreases real estate values.

Through insufficient attention to the problems posed by erosion, runoff, and aesthetic damage, hillside development can have a far-reaching impact on a region's land, water, economic, and scenic resources. Yet with proper planning,

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hillsides can be developed in a manner compatible with hillside ecology.

Although there are many factors that determine where hillside development is appropriate, it is safe to say that low slopes (those with 1 to 10 percent grade) offer few major obstacles to development, although they are susceptible to erosion if careless removal of the groundcover occurs. Gentle slopes are capable of supporting low-density residential use, but more intense uses should be allowed only with caution.

Density should be lower on moderate slopes (10 to 25 percent grade) because severe erosion and land slippage may result when the groundcover is disturbed. Subsequent sedimentation is a serious possibility, fouling and clogging streams and disrupting the natural water courses. If the soils and drainage on moderate slopes are not conducive to construction, structural damage can result.

On extreme slopes (above 25 percent grade), development will almost certainly increase the amount and velocity of runoff, causing severe erosion. Since development is risky and very expensive, these areas might be set aside for recreation since they often are of great scenic beauty.

Slope in a region may be determined from a topography map, readily available from the National Topography Map Series of the USGS. Most states now have a complete coverage at 1:24,000 and 1:62,500. Relief is shown by 20-foot contour lines on 15-minute maps and 10 feet on $7\frac{1}{2}$ minute maps. If the use of contours is wanted for an overlay map, the USGS can furnish maps with only the brown overprint that indicates contour lines.

Other sources for topographic maps in some states are state geological surveys and state planning agencies. In addition, the U.S. Army Topographic Command has maps for some areas of the country. Soil survey maps usually provide some topographic information—mainly that relevant to erosion, location of ridge lines, and direction of drainage. If an area lacks current maps, the USGS will pay up to one-half the cost of topographic mapping carried out in cooperation with state or local governments.

It will be easy to use contour maps for public presentation if, instead of using an overlay of contour lines, the degrees of slopes are aggregated into three or more groups—low, moderate, extreme, etc.—and each assigned a different color. This will at once reduce the complexity of the map and, at the same time, highlight only those areas that have significant slope that will have an effect on planning development.

Hydrology

The principal reasons for controlling development on or near water are to protect watersheds, to preserve the quality and quantity of the water supply, and to prevent damaging floods. Urban areas require great quantities of water for industrial, business, and domestic use. In regions where agriculture is a major land use, water availability and quality are as important as soils. Since, in any case, surface waters are essential for regional aesthetic and economic benefits, they should be inventoried thoroughly.

The desired degree of control varies for the type of area where development would affect surface water. Permanent bodies of water—lakes, rivers, streams, estuaries, etc.—are valuable as a source of water supply, food, and recreation, for waste dispersion, transportation, and power generation. All lakes and ponds may become degraded, become marsh and then dry land. This natural evolution, called entropy, may be hastened by uncontrolled development since pollution and erosion resulting from urbanization can destroy the water's balanced nitrogen and oxygen cycles and its recreation potential.

Streams and creeks have a direct effect upon the quality and quantity of a region's water resources. Qualitatively, streams and creeks replenish groundwater, river flow, and reservoirs; they are a major natural source of water to the system and if they become polluted, then a region's entire water resource, both above and below ground will suffer. Quantitatively, streams and creeks may carry increased runoff or sediment from improper watershed development and increase or cut off regular water flow to groundwater formations. Similar quantitative effects can be seen, on a larger scale, in lakes and rivers.

Since streams and creeks contribute to a region's total water resource and general environmental well-being, the planning of development within a region must expand beyond the watercourses themselves and look to the whole concept of the watershed system—drainage, wetlands, lakes, reservoirs, and groundwater filtrations. Since streams and creeks are major networks that transport nutrients and sedimentation, as well as pathways functioning as routes for various birds and mammals, they are a matrix of the watershed, binding hillsides, woodlands, and wetlands into one inseparable, interdependent ecological community. Because streams and creeks are an intricate part of the hydrological and nutrient cycles, and because of their intricate relationship to so many environmental communities and processes, the health of the watercourses serves as an index to the health of the entire system.

Floodland is the land area adjacent to a body of water which is covered by excess water during periods of flooding. This water carrying capacity of floodlands is an essential function and is why floodlands are so valuable. Floodlands may be divided into zones based on the frequency of inundation, often categorized as channels, floodways, and floodplains. It is especially important to make these distinctions for land-use and development controls which are important since building on floodlands endangers human life and property. Furthermore, floodplains often provide valuable recreation land. Filling, damming, or leveling floodplains decreases storage capacity and increases flood velocity and the flood potential downstream. Agriculture is often an ideal use in floodplains as the soils are very fertile, there is usually substantial groundwater, and the effect on flat land is minimal.

Wetlands—tracts of low-lying lands that are saturated with moisture and usually overgrown with vegetation—act as sponges that absorb excess runoff and thus reduce flooding potential. They also provide important wildlife habitats and recreational areas and have educational and scientific value. Some wetlands have agricultural value; they often have scenic beauty. Wetlands are frequently found about estuaries—water passages where the tide meets a river current, especially an arm of the sea at the lower end of a river. As breeding

grounds for a variety of organisms, estuaries are particularly intolerant of waste disposal, dredging, filling, and upstream pollution since these activities can destroy important animal and plant communities.

Subsurface waters in the form of aquifers—water-bearing layers of sand, gravel, or porous rock—are as important and delicate as surface waters. As a major source of water supply, their quality must be maintained and the removal of water from them must not exceed the rate of replenishment. Aquifers are replenished in recharge areas—areas of interchange between the aquifer and the earth's surface and the point where precipitation and surface water infiltrate the aquifer. Wise planning of development in recharge areas is particularly important because of the danger of polluting the water supply.

Aquifers act as reservoirs, filters, and a balance in the hydrological system of a community and region. They are natural reservoirs for groundwater used in drinking and irrigation and must be protected because the amount of groundwater entering the aquifers is used by many types of communities: some areas can draw upon surface water supplies, such as lakes and streams, for their drinking water and irrigation needs, but many communities, particularly rural ones,depend upon groundwater or wells drilled into aquifers for their water.

Percolation of precipitation through soil and overlying formations filters many impurities before they reach the aquifer; as groundwater moves through waterbearing formations of aquifers, it is filtered further. But this filtering property of aquifers is not absolute. Leaking septic tanks and sewage lines, unsealed landfill sites, and sewage and soil waste disposal sites can allow pollutants to pass directly into groundwater reserves where the water table is very near the surface, the soil mantle is very thin, or the aquifer is very permeable. In these cases, concern must be directed toward the quality of water entering the aquifer.

Similarly, pollution or depletion of surface water affects groundwater and can contaminate an entire system since aquifers are directly connected to lakes, streams, and wetlands through gradual seepage. Alternately, some of these lakes,

streams, and wetlands replenish their water supply from the aquifer when conditions are dry. Therefore, pollution factors must be checked to maintain the aquifer-stream-lake-wetland reciprocal balance and attention must be focused on the quality and quantity of water exchanged between groundwater and surface reserves.

Because aquifers serve these three functions—they act as a reservoir, as a filter, and as part of the hydrological cycle—they are important regional resources and are particularly sensitive in terms of development. It is best to avoid development over deep aquifers.

Hydrology studies include subsurface water as well as surface water. The Water Information Group of the USGS has information in the form of maps, atlases, and reports that cover various characteristics of the hydrological cycle. They have a free publication for each state, "Water Resources Investigation," which includes a list of a selected number of reports prepared for each state. Depending on detail, the scale of the maps varies from 1:24,000 to 1:250,000. For surface water only, a local planning agency may request a copy of the blue overprint from the standard USGS topographic map. These hydrological maps and reports containcmuch information about the quality and quantity of ground and surface waters. For a given area, hydrological information includes analyses of the elevation levels of major floods, depth to mineralized groundwater, saline water, chemical qualities of surface water, and temperature of surface water. Aquifers, floodplains, and wetlands should be highlighted on the hydrology map.

Soils

Soil composition directly affects building and highway construction, septic systems, water availability, and agriculture. Since everything that touches the soil is affected by it, it is essential that accurate soil data are used in land-use planning. A soil suitability study should be used to assess (1) the engineering property of soils in order to determine the appropriate pattern of residential, commercial, industrial, agricultural, and

recreational use; (2) the suitability of soils for sewage dispersion, drainage systems, and water storage; (3) the soil and plant relationship so that prime agricultural areas can be identified; and (4) the location of important mineral deposits.

Soils with a high moisture content, whether due to a high water table or poor drainage, are suitable only for floating or other specially built structures if supplied with public water and sewerage. Wet soils important because they store water, can be easily contaminated if septic tanks are allowed. In development, draining and filling should be permitted selectively if they do not interfere with the water supply.

Dense soils inhibit and are often impervious to the free downward flow of water; such soils usually have a high proportion of clay in them. Impermeability may cause tanks to overflow and contaminate the water supply, and like wet soils, dense soils are unsuitable for development without public water and sewer systems.

Poor load-bearing soils are usually easy to compact because of their moisture content or because excessive internal spaces are present. (Filled land or industrial or municipal waste piles often have these characteristics.) Such soils are unable to support structures such as buildings and paved roads, and are thus generally unsuitable for intensive development. Recreation and agriculture, as well as certain types of light or flexible structures, are adaptable to poor load-bearing soils, but heavy structures require anchoring to bedrock.

If a local planner is unable to interpret soil types into appropriate use categories (e.g., soils good for residential development, soils for agriculture), the local Soil Conservation Service (SCS) office can prepare such interpretive maps and reports. For this reason, it is a good idea to work closely with the local office.

A soil survey is based upon aerial photography and the maps are usually printed at a scale of 3" = 5,000 (3:60,000) or 1" = 1 mile. They are accompanied by a discussion of the functional classification of the soils in the area based upon a nationwide classification system, including a description of each kind of soil and general information about the agriculture and climate of the area. Most surveys supply information such as the most

important soils for potential agricultural uses, what types of wildlife are likely to be associated with certain types of soils, nonagricultural plant material and its relationship with soil types, likely flood and drainage areas, and soil properties affecting engineering uses. This basic information provides a suitable foundation for planning decisions.

Geology

Geology involves not only bedrock and other mineral foundations covered by a layer of soil, but also areas and planes of exposed rock. Geology has a fundamental bearing upon surface and subsurface drainage patterns and a site's ability to support structures.

In some areas, the underground formations are incapable of supporting heavy loads and development can cause subsidence, landsliding or other earth movement. These weak areas are usually associated with certain geologic characteristics, a type of bedrock or the manner in which layers of rock and soil are arranged, for example. Areas such as these may be capable of supporting only low-intensity development and may require special construction methods to assure slope stability.

Many problems arise because investigations often neglect to identify the nature and location of subsurface mineral deposits. Wherever mineral extraction is feasible, the detrimental effects of such extraction must be minimized and provisions must be made for site re-use after the extractive operations are concluded. With proper planning, mineral extraction can be accomplished without negative effects on the environment, but this is possible only if planners know beforehand where the deposits are located so that land use before and after the operation can be controlled. If mineral deposits are found after development has taken place, extraction operations must be precluded.

One of the problems encountered when collecting geological data is that too often they are outdated and have varying degrees of accuracy in many areas of the country. Furthermore, interpretation requires experts. Geological maps of

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1:24,000 to 1:63,363 are available for only about 25 percent of the U.S. and smaller scale maps (1:250,000) are available for less than one-third of the states and approximately 40 percent of the country. Maps showing geological structure and mineral resources in a region are available from the USGS.

Vegetation and Wildlife (Biotic Resources)

Too often, if vegetation and wildlife are considered at all in land-use planning, it is only in terms of parks and other open spaces for recreation. Little thought is given to the ecologically delicate relationship among plants, animals, and man. Since uncontrolled development and the subsequent loss of groundcover can often have serious consequences, it is important that planners should have at least a working acquaintance with ecology and should gather as much information as possible about areas in their region sensitive to development.

Development should be watched especially in woodlands since they play an important role in the protection of watersheds. Aside from the aesthetic pleasures that trees, shrubs, and other vegetation provide, they also prevent erosion by binding the soil together with their roots. In addition, as water percolates downward, plantlife aids in its cleansing.

Unique vegetation habitats should be preserved for scientific and educational reasons. Virgin stands of forest, unbroken prairie, and other features support complex animal communities that are intrinsically important. The tolerance of these areas to intensive nearby development varies but must be taken into consideration in any event.

The green overprints of the USGS topographical maps may be used to determine dense woodland cover, but for a more detailed and accurate inventory, local sources have to be used. Wildlife and botany experts at nearby schools are often valuable aids for identifying unique habitat areas and routes of migratory animals that are worthy of protection. State fish and game departments may also have to be consulted. In short, gathering data on vegetation and wildlife is a piecemeal process. Site-specific information on biotic resources simply does not exist for most regions.

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The Ganges Water Machine

Roger Revelle and V. Lakshminarayana

The river Ganges and its tributaries, and the flat and fertile plain through which they flow, are one of earth's great natural resources. For thousands of years abundant water and generous land have provided the foundation for a highly developed civilization based on agriculture and for one of the world's largest concentrations of human populations. But farming is mainly traditional and at a subsistence level, with little surplus, and as a result the population has remained overwhelmingly rural and most people are desperately poor. Although irrigation from canals and wells has been practiced for millennia, chiefly as a protection against the uncertainties of the monsoon rains, the water resources are largely untapped; the small fraction of water used for irrigation is poorly managed and its productivity is low.

Deeply embedded cultural, social, and economic problems inhibit modernization of agriculture and fuller utilization of the water resources. Capital investments and technological changes on a large scale are also required. As experience elsewhere shows, the introduction of technological changes on the required scale might break the chains of tradition and injustice that now bind the people in misery and poverty.

Ganges and Its Tributaries

The Ganges Basin covers parts of four countries, India, Nepal, Tibet, and Bangladesh; eight Indian states, Punjab, Uttar Pradesh, Haryana, Himachal Pradesh, Rajasthan, Madhya Pradesh, Bihar, and West Bengal; and the Union Territory of Delhi. We shall consider that part of the Basin that drains into Bangladesh through the great distributary called the Padma. The other main distributary, called the Bhagirathi, has long been moribund and now serves only as a spill channel for Ganges floods. Within India, the Ganges Basin, as we have defined it, covers 800,000 square kilometers (*1*). Its population is about 225 million, somewhat more than that of the United States, which covers nearly ten times the area. At present rates of growth, the population will double in 30 years.

The fundamental problems of land and water development in the Ganges Plain arise from the highly seasonal flow of the river and its tributaries. Nearly 84 percent of the rainfall occurs from June through September, and 80 percent of the annual river flow takes place during the 4 months of July through October.

The average annual flow of the Ganges at the Hardinge Bridge in western Bangladesh is 36.2×10^6 hectare-meters, and the monsoon flow from July through October is 28.9×10^6 ha-m. During the remaining 8 months of the year, the river carries only 7.3×10^6 ha-m (*2*). Part of this dry-season flow comes from groundwater in the Ganges Plain, and the remainder comes mainly from the Himalayas.

Even at present, the dry-season flow of the Ganges is barely sufficient for the needs of India and Bangladesh. If irrigation with either groundwater or surface water continues to be developed along the lines of present programs, the dry-season flow will be continually reduced. In order to develop the full irrigation potential of agricultural land without unacceptable reduction of the dry-season flow of the Ganges, it will be essential to store a portion of the monsoon waters for use in irrigation. Because of the steep slopes of the Himalayan foothills and the flatness of the Ganges Plain, surface sites for storage are scarce, and costs per unit volume of surface-stored water are several times higher than in many other parts of the world. On the other hand, there are great possibilities for underground storage, which should be relatively inexpensive.

Present Needs for the Ganges Low Flow

Irrigation in Bangladesh. The average rainfall in Bangladesh is higher, and the potential for increasing groundwater recharge from rain is greater, than in the Indian part of the Ganges Plain. Unfortunately, there is a wide variation among different districts, just as in India. Revelle and Herman (*3*) estimated that water from the Ganges is needed in Bangladesh during the low flow season to supplement groundwater irrigation in three districts in the northwestern part of the country. In the southwest, where the groundwater is saline, Ganges water is the sole irrigation source. In other districts some Ganges water is needed to minimize saltwater intrusion. The sum of these needs totals about 1.8×10^6 ha-m.

Diversion of low flow waters for Calcutta port maintenance. Part of the Ganges waters during the low flow season must be diverted at the Farakka Barrage through the Bhagirathi into the Hooghly River, to maintain a sufficient freshwater discharge past the port of Calcutta. We learn that the feeder channel at the Farakka Barrage has been designed and constructed for a capacity of about 0.29×10^6 ha-m per month. This is more than half the average low flow of the Ganges during the 3 months of February through April. These are also the months when the need for surface water is most critical in western Bangladesh and when the flow into the rivers from groundwater is minimal.

Navigation on the main stream. Economic development in both India and Bangladesh would be hastened if the Ganges could be used as a great international waterway for transport of heavy or bulk materials. Conversely, as development proceeds, the needs for year-round water transportation on the river will rapidly grow. A water route down the Ganges and up the Brahmaputra into Assam would yield large benefits today.

Year-round transportation will depend directly on maintaining a sufficient dry-season flow. Even for relatively shallow barges and moderate-sized ships, an average river depth of 5 m would be desirable. With a width of 900 m and a velocity of flow of 0.35 m per second, this would require a minimum discharge of 1550 m^3/sec, or about 3.2×10^6 ha-m during the eight dry months.

Downstream water quality. The growth of modern agriculture in India,

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based on irrigation development, and the construction of heavy industries with large water demands will inevitably worsen the quality of the Ganges waters during the low flow season. A large variety and quantity of chemical and organic residues, including chemical fertilizers and pesticides, will be carried in the return flows to the rivers. Although it is difficult to make a quantitative estimate of the amounts that will be involved, one of the most forceful arguments for maintaining the low flow is to ensure that a sufficient volume of water remains in the rivers to dilute and oxidize these residues.

Utilization of Monsoon Flows

Taking into account the irrigation potential in the kharif (monsoon) and rabi (winter) growing seasons, at least 25×10^6 gross cropped hectares in the Ganges Plain could be fully irrigated in addition to the present partially irrigated gross area of about 12.5×10^6 hectares. With modern agricultural technology, the production of food grains from the irrigated area could be more than 150×10^6 metric tons, enough to provide a satisfactory diet for more than 600 million people. These possibilities can be realized, however, only by integrated development of the surface and groundwater resources of the Ganges Basin. The time required would be of the order of 25 years, but benefits from projects which would be compatible with the integrated system could be obtained at every stage.

The key to successful development will be storage and beneficial use of a major part of the monsoon flows of the Ganges and its tributaries, which now run to the sea largely unused. Utilization of these high flows for irrigation throughout the year would have a further advantage in ameliorating flood damage (*4*).

In the past, irrigation development in both the kharif and rabi seasons has been largely based on diversion of the river flows and on utilization of a portion of the underground waters which would otherwise seep back into the rivers. The low flows of the Ganges and its tributaries are being progressively reduced, even though the present river volume during the 8 months of the dry season is just about sufficient for municipal and industrial water supply and waste disposal, maintenance of water quality, diversions to protect the port of Calcutta, needs of Bangladesh including prevention of salinity intrusion, and future needs for navigation.

Besides the limited possibilities for surface storage, there are at least five ways in which a portion of the monsoon flows could be stored underground. Infiltration into the water table in the monsoon season could be increased by (i) water spreading in the piedmont deposit north of the Terai belt of springs and marshes; (ii) constructing bunds at right angles to the flow lines in uncultivated fields to slow down runoff and increase infiltration; (iii) pumping out the underground aquifers during the dry season in the neighborhood of nallahs (natural drains) which carry water during the monsoon (*5*); (iv) pumping out groundwater during the dry season along certain tributaries of the Ganges to provide space for groundwater storage; and (v) increasing seepage from irrigation canals during the monsoon season by extending the network of canals, distributaries, and water courses for kharif irrigation and pumping out this seepage water during the dry season. In addition, evaporation losses from the water table might be reduced by lowering it below the level of appreciable evaporation. Finally, it may be beneficial to export some monsoon water from the Basin to the areas to the south and west where irrigation could be extended if firm water supplies were available.

In Table 1 we have estimated the likely increase in irrigation water supplies produced by some of these devices. A large increase could be obtained by construction of barrages and "leaky" canal systems for surface irrigation of a large part of the cultivated area, including an increased area of rice cultivation, during the kharif season, plus wells to recover the underground seepage during the rabi season. Recharge of aquifers along certain Ganges tributaries could provide an equally large increase of rabi irrigation supplies.

Possible use of aquifers near rivers to store monsoon water. There is good reason to believe that in many places the underground aquifers are well connected to the rivers and are highly permeable. For example, in one region where a groundwater survey was made (*6*) the seasonal contours of the water table on both sides of a large tributary show that this river is a drain which carries off perhaps 0.12×10^6 ha-m of water that seeps into it during the dry months from the underground aquifers. If these contours could be reversed by large-scale pumping of the underground waters in the dry season, the aquifers could receive and store a large part of the monsoon flow of the river. We believe that similar underground storage of river floodwaters could be carried out along many tributaries of the Ganges.

It would be necessary to lower the

Table 1. Possible future water budget for the Ganges Plain. Except where noted, values are calculated from data in *Report of the Irrigation Commission, 1972* (*1*).

Source or sink	Volume ($\times 10^6$ ha-m) during Low flow season (November to June)	High flow season (July to October)
Supplies		
Present average river flow at Bangladesh boundary	7.3*	28.9*
Evapotranspiration from present surface storage and river diversion (1968–1969)	1.8†	1.8†
Evapotranspiration from present well irrigation (1968–1969)	1.3†	0.7†
Additional surface storage (under construction or potential)	1.5	−1.5
Reduction of groundwater evaporation by pumping down water table	0.8†	
Increased infiltration of rainfall by bunding in uncultivated areas	0.7†	−0.7†
Potential additional underground storage	6.0‡	−6.0‡
Transfers out of basin (such as "Ganga-Cauvery Link")		−1.8
Total supplies	19.4	21.4
Uses and excess flows		
Consumptive use in present irrigation (1968–1969)	3.1	2.5
Consumptive use in potential additional irrigation	9.0†	6.0†
Diversion to Hooghly River at Farakka Barrage for Calcutta maintenance	2.3‡	
Needs for irrigation in Bangladesh	1.8‡	
River navigation and waste disposal	3.2‡	
Monsoon flow at Bangladesh boundary§		12.9
Total uses and excess flows	19.4	21.4

* From (*2*). † See (*9*). ‡ See text. § Estimated by differences.

water table to a greater depth at the beginning of the monsoon season than that required simply to produce the storage volume. Moreover, the aquifer directly under the river would need to be pumped down close to the average depth. In the rivers of the western part of the Plain, where the dry-season flow comes largely from groundwater seeping out of the river banks, the low flow discharge during the first year would be removed by the pumping, and thereafter the river would be virtually dry during the months of November to June. Several years would be required to obtain the full storage potential. Each year the water table at the beginning of the monsoon season would be pumped deeper than the year before, until an equilibrium would ultimately be reached.

Pumping out Groundwater during Low Flow Season

For a rough estimate we may assume that along 3200 km of the system of larger tributaries of the Ganges (about a quarter of the total length) large well fields could be constructed which would produce storage space by pumping out the groundwater during the low flow season. With well fields 6 km wide on either side of the river, the area covered would be 3.8×10^6 ha. If we assume that the well field capacity is 2.25 m^3/sec per kilometer (that is, 1.12 m^3/sec on each side of the river per kilometer of length) and the storage coefficient of the aquifer is 0.25, then the water table will be lowered, on the average, about 12 m at the end of 8 months of continuous pumping. All the wells need not be of the same capacity. It is necessary only to design the well spacings and discharges in such a way that we pump out a trough of 12 m below the river bed. The method used for finding the depression of the water table is given below.

The drawdown due to pumping in an aquifer is given by

$$s = \frac{Q}{4\pi T} \int_{\frac{r^2 S}{4Tt}}^{\infty} \frac{e^{-u}}{u}\, du \qquad (1)$$

where the drawdown $s = h_1 - h$ (m), h_1 is the initial saturated thickness of the aquifer (m), h is the height of the water table during pumping (m), Q is discharge (m^3/day), T is the coefficient of transmissibility (m^2/day), S is the storage coefficient (dimensionless), t is time since pumping started (days), and r is the distance from the pumping well (m).

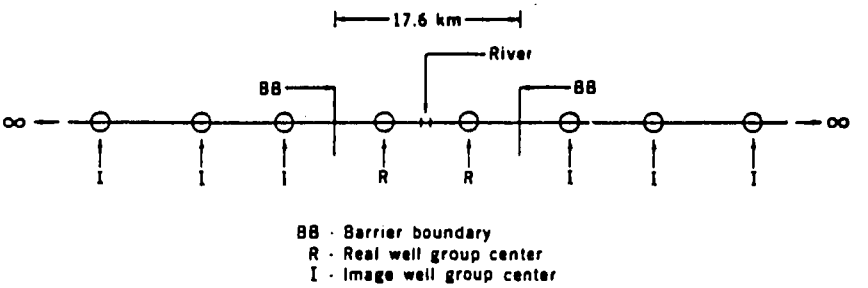

Fig. 1. Location of real and image well groups.

Equation 1 holds strictly only for a confined aquifer which is isotropic and homogeneous. However, it can be used for an unconfined water table aquifer (as in the present case) provided drawdown is small compared with the original saturated thickness of the aquifer. In the Ganges Plain the aquifers are quite thick, and the drawdown of the water table will be small compared with the initial saturated thickness of the aquifer; consequently, we can apply Eq. 1. There are other assumptions involved in the derivation of Eq. 1. Revelle and Herman (*3*) showed that, although these assumptions are not strictly valid in the present case, the equation can still be used to give a fairly good solution.

Equation 1 is the solution of the differential equation

$$\frac{\partial^2 h}{\partial r^2} + \frac{1}{r}\frac{\partial h}{\partial r} = \frac{S}{T}\frac{\partial h}{\partial t} \qquad (2)$$

subject to certain simple boundary conditions. Since Eq. 2 is linear, the superposition principle can be used to find the solution when more than one well is being pumped in the aquifer. Equation 1 is obtained on the assumption that the aquifer is areally infinite. If we have boundaries then we must use the method of images.

In the present calculation we have assumed that there is a natural groundwater divide at a distance of 8 km on either side of the river. This is approximately true for many of the tributaries that feed the main tributaries of the Ganges. The natural groundwater divide acts as an impervious barrier. The presence of the river itself can be ignored in the computations, since during the dry season the quantity of flow in many Ganges tributaries will be small compared with the quantity of pumping. Grouping the wells in pumping centers, we will have the real and image wells shown in Fig. 1. Because of the assumed existence of an impervious boundary on either side of the river, there will be an infinite number of images. However, only a few need to be considered, since the effect of image wells very far off will be small near the river.

Equation 1 is applied repeatedly for all the real and image wells, and we obtain a lowering of the water table, on the average, of about 12 m at the real wells.

Table 2. Possible river reaches for underground storage of monsoon flows (assuming storage of 1800 ha-m per kilometer of river). Estimated monsoon and dry-season flows are based on U.N. data (*2*).

River	Length of well fields (km)	Monsoon flow ($\times 10^6$ ha-m)		Dry-season flow ($\times 10^6$ ha-m)	Ratio of dry-season to stored flow (%)
		Stored underground	Remaining in river		
1) Ganga to Yamuna	720	1.3	0.1	0.3	23
2) Ramganga	560	1.0	0.1	0.2	20
3) Yamuna system	1440	2.6	0.3	0.7	27
4) Gumti and Sai	610	1.1	0.1	0.3	27
5) Gagra, Sarda, and Rapti	1280	2.3	3.2	1.2	52
6) Son	640	1.2	1.0	0.5	42
7) Buhri Gandak and Baghmati	720	1.3	3.2	1.0	77
8) Below the Kosi, including Mahananda	400	0.7	1.1	0.4	57
Totals	6370	11.5	9.1	4.6	42
Sum of 1 to 4	3330	6.0	0.6	1.5	25
Sum of 5 to 8	3040	5.5	8.5	3.1	56

Recharge of Groundwater Mound by Monsoon Flow

When pumping stops at the end of the dry season there is some flow into the trough from the sides. It is therefore assumed that we have a net trough with an average depth of 10 m to be partly filled by monsoon flow in the river.

The growth of the groundwater mound resulting from infiltration of the monsoon flow in the river is computed by using the following equations given by Hantush (*7*)

$$h^2 = h_1^2 + \frac{WT}{KS} t \left\{ 2 - 4i^2\, Erfc\left[\frac{L-x}{\left(4\frac{T}{S}t\right)^{\frac{1}{2}}}\right] - 4i^2\, Erfc\left[\frac{L+x}{\left(4\frac{T}{S}t\right)^{\frac{1}{2}}}\right]\right\} \quad \text{for } x < L \qquad (3)$$

$$h^2 = h_1^2 + \frac{WT}{KS} t \left\{ 4i^2\, Erfc\left[\frac{x-L}{\left(4\frac{T}{S}t\right)^{\frac{1}{2}}}\right] - 4i^2\, Erfc\left[\frac{L+x}{\left(4\frac{T}{S}t\right)^{\frac{1}{2}}}\right]\right\} \quad \text{for } x > L \qquad (4)$$

where the symbols other than the ones already used are: W, recharge rate through the bed of the river (m/day); K, coefficient of permeability in the aquifer (m/day); t, time during which recharge takes place (days); L, half-width of river (m); x, distance from center of river (m); and

$$Erf(x) = \frac{2}{\pi^{\frac{1}{2}}}\int_0^x e^{-\zeta^2} d\zeta$$

$$Erfc(x) = 1 - Erf(x)$$

$$4i^2\, Erfc(x) = Erfc(x) - 2x\, iErfc(x)$$

Since Eqs. 3 and 4 are implicit, a trial and error procedure or a graphical method has to be adopted for solution. For example, assume $t = 15$ days. Then, using $T = 4650$ m²/day, $L = 150$ m, $W = 0.61$ m/day, $K = 15.2$ m/day, $S = 0.25$, $h_1 = 300$ m, and $t = 15$ days, we get $(4Tt/S)^{1/2} = 1055$ m and $L/(4Tt/S)^{1/2} = 0.144$. From Eq. 3 we find

$$h^2 = (300)^2 + \left(\frac{0.61}{15.2} \times \frac{4650}{0.25} \times 15\right)(0.56) = 96{,}270 \text{ m}^2$$

Therefore

$$h = 310 \text{ m}$$
$$h - h_1 = 10 \text{ m}$$

Thus the time for the water to rise 10 m at the center of the recharging strip is 15 days.

The height of the groundwater at a distance of 600 m from the center of the river can be computed as follows

$$\frac{x-L}{\left(4\frac{T}{S}t\right)^{\frac{1}{2}}} = \frac{450}{1055} = 0.43$$

$$\frac{x+L}{\left(4\frac{T}{S}t\right)^{\frac{1}{2}}} = \frac{750}{1055} = 0.72$$

Using Eq. 4 we obtain

$$h^2 = (300)^2 + \left(\frac{0.61}{15.2} \times \frac{4650}{0.25} \times 15\right)(0.35 - 0.14) = 92{,}350 \text{ m}^2$$

Therefore

$$h = 303.5 \text{ m}$$
$$h - h_1 = 3.5 \text{ m}$$

Similarly at 1500 m, we obtain

$$h^2 = (300)^2 + \left(\frac{0.61}{1512} \times \frac{4650}{0.25} \times 15\right)(0.016 - 0.005) = 90{,}123 \text{ m}^2$$

$$h = 300.2 \text{ m}$$
$$h - h_1 = 0.2 \text{ m}$$

Thus, assuming that the rate of recharge is 0.61 m/day, which is a rather conservative figure, the height of the water mound at the end of 15 days will be 3.5 m at a distance of 600 m and 0.2 m at a distance of 1500 m. From this we can compute the quantity of monsoon water abstracted as 1×10^6 ha-m. After 15 days there will still be some recharge, because some of the bank flow from the river will continue to fill the trough. Thus, during the first year of operation somewhat more than 1×10^6 ha-m will be extracted from the monsoon flow. When this is spread over the groundwater basin 17.5 km wide, it will raise the water table by 0.75 m. To this we may add a rise of the water table by 0.6 m caused by 15 cm of net rainfall infiltrating to the water table. Thus, at the beginning of the second year of operation the water table will be about 8.6 m below the level at the beginning of the first year.

During the second year of operation the water table will be lowered by 10 m to a depth of about 18.6 m before the monsoon flow begins. The time taken to raise the water table 18.6 m at the center of the river bed during the monsoon comes to 33 days. At this time the height of the groundwater mound will be 7.5 m at a distance of 600 m and 1.5 m at a distance of 1500 m. The total quantity of monsoon water extracted will be about 2×10^6 ha-m, again ignoring the contribution from bank flow. This will raise the water table by about 1.5 m. Adding about 0.6 m due to infiltration of rainfall, the depth of the water table at the beginning of the dry season in the following year will be 16.5 m below the initial level.

During the third year of operation this will again be lowered by 10 m, leaving the water table at a depth of about 26.5 m at the beginning of the monsoon. The time taken for the water table under the river to rise 26.5 m is about 70 days. At this time the height of the groundwater mound will be 15 m at a distance of 600 m, 5 m at a distance of 1500 m, and 0 m at a distance of 3000 m. Thus, the amount of water extracted from the monsoon flow, ignoring the contribution from bank flow, will be about 6×10^6 ha-m. At the end of the monsoon the water table will be at an average depth of about 22 m over the cross section of 17.5 km.

By similar computation, we can show that during the fourth year of operation the depth of the water table at the end of the pumping season will be 32 m, and in the 120 days of the monsoon season we will extract from the monsoon about 9×10^6 ha-m. The depth of the water table at the end of the monsoon will be about 25 m below the initial level 4 years earlier.

From the following year onward, the water table will be stabilized at these levels by pumping out a quantity equal to consumptive use plus surface drainage plus return infiltration to the groundwater table.

Figure 2 shows the growth of the groundwater mound under uniform recharge from the river for the stated values of the parameters. Because different scales have been used in the horizontal and vertical directions, the slope of the water table appears to be steep. Actually its profile will be very flat. For instance, at the end of the first monsoon period the slope will be approximately 1 to 170; at the end of the fourth monsoon period it will be approximately 1 to 140. We can therefore use the bank storage equations given by Cooper and Rorabaugh (*8*) for a horizontal water table, as shown in the next section.

With any particular set of assumed parameters, equilibrium will be reached in the number of years required to lower the water table to a depth such that 120 days (the length of the monsoon season) will be required for the

infiltration mound to reach the bed of the river. For example, assuming a storage coefficient of 0.15, a transmissibility of 2800 m^2/day, and a pumping rate of 1.35 m^3 sec^{-1} km^{-1}, an equilibrium depth of 35 m at the end of the monsoon season will be reached in about 12 years. From that time onward, 6×10^6 ha-m will be stored each year.

During the monsoon season the rivers in northern India always carry some water, with flood peaks occurring after every heavy storm. Thus, even if the duration of the flood wave is short, say 6 to 12 hours in the smaller streams (longer in bigger tributaries)—recharge will continue under the lesser flow that prevails before and after its passage. Hence we can assume that about 120 days is always available for recharge during the monsoon season.

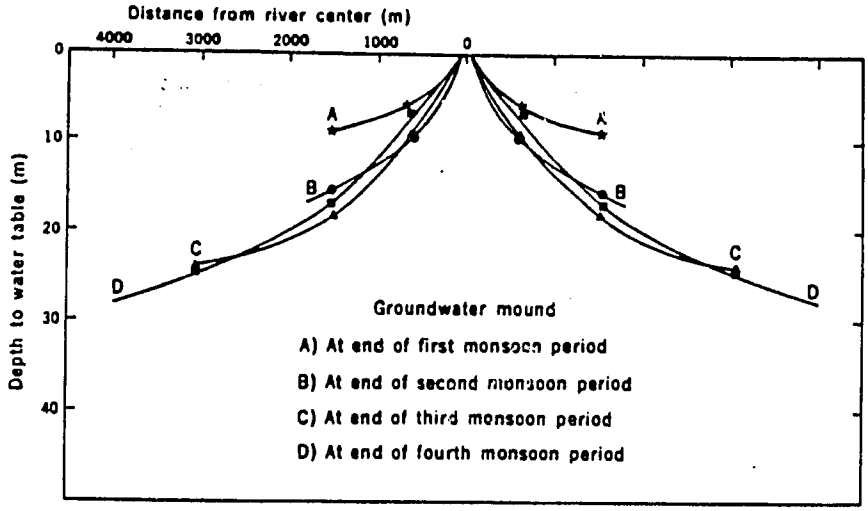

Fig. 2. Growth of groundwater mound under uniform recharge from river.

Advantages of Aquifer Storage

Flood amelioration. During the flood wave there will be much more bank storage than there is now along the tributaries where the water table has been lowered by pumping. This will supplement the aquifer storage described above in reducing downstream flooding. The amount of bank storage can be computed from the equations of Cooper and Rorabaugh (*8*).

Assuming a flood duration of 3 days, a flood crest of 3 m, aquifer transmissibility of 4650 m^2/day, and a storage coefficient of 0.25, the amount of bank storage 2 days after the beginning of the flood will be 2.3×10^5 m^3/km. This temporary bank storage is 50 percent of the water entering the aquifer during the same 2-day period; 75 percent of the bank storage will return to the river during the following 7 days.

Use of stored monsoon waters in irrigation. The area to be irrigated with the pumped waters would be larger than that of the well fields. Assuming 6×10^6 ha-m of storage from the monsoon flow, and adding the rainfall infiltration of 0.15 m, the gross irrigated area would be 17.5 to 19 m-ha. Here we assume that an amount of water equal to 10 percent of consumptive use by evapotranspiration is allowed for drainage to maintain a salt balance, or alternatively the original dry season flow of the river is returned downstream of the well fields in order to maintain the low flow. If the irrigated areas, including the zone of intense pumping, were located in strips along both sides of the rivers used in the scheme, the average width on each side of the rivers would be roughly 27 to 30 km.

Allowing for 20 percent return infiltration of the pumped water, the total pumping from the irrigated area during the dry season is about 10.5 $\times 10^6$ ha-m, requiring a total well capacity of around 5000 m^3/sec. If the well fields are 6 km wide on either side of the river, more than half the net volume pumped would need to be transported to the outer 21- to 24-km strip in surface conveyance channels. Since unlined channels inevitably leak into the ground a considerable fraction of the water they carry, this surface distribution system could, with proper management, also be used as a groundwater storage mechanism. For example, if the channels extended to the river, they could be used as inundation canals for irrigation during the monsoon season, and 30 to 50 percent of the water carried in them would be expected to seep downward to the aquifer.

Possible Tributaries for Monsoon Storage

Table 2 shows possible river reaches along which the underground storage scheme for the monsoon waters might be used, and Table 1 shows a possible future water budget for the Ganges Plain. It will be seen that in the western tributaries the initial dry-season flow would be about 25 percent of the water coming from the rivers into the aquifer. A portion of the pumped water would be needed for water supply and waste disposal for cities and towns along these rivers; return flows from irrigation could also be used for waste disposal. In either case, conveyance channels or pipes for the pumped water would be required. In the central and eastern plain, the dry-season flow probably comes largely from the Himalayas and equals 42 to 77 percent of the quantity of stored monsoon water. For economy in pumping and ease in maintaining the low flow water supplies for cities and towns, it would probably be desirable to construct diversion barrages upstream of the well fields and lined channels to carry the diverted water downstream of these fields.

Costs and Benefits of the Storage Scheme

Power requirements for pumping stored monsoon waters. Assuming an average pumping lift of 30 m, the net electrical energy required to pump 10.5 $\times 10^6$ ha-m would be 8.75×10^9 kilowatt-hours. With an overall efficiency of 67 percent, including transmission losses, the energy required at the generating plant would be 13×10^9 kwh, corresponding to an installed power capacity of 3000 megawatts at 50 percent load factor.

The electrical power requirement could be supplied by mine-mouth electric generating plants in the Raniganj-Jharia coal fields in Bihar, or by utilizing a small fraction (possibly less than 15 percent) of the enormous potential hydroelectric capacity of Nepal. (It is sometimes said that the force of gravity,

expressed in falling water, is Nepal's principal natural resource.)

All the methods we have described for underground storage of monsoon waters would involve use of electric or diesel power for pumping. Because of the greater depth of pumping, the energy requirements for the river storage scheme would be larger than for other methods. But the ratio of benefits to costs would still be high.

Annual costs and benefits of the storage scheme. At $0.02 per kilowatt-hour, the annual power cost would be $260 million, or about $14.50 per gross irrigated hectare. At $0.005 per kilowatt-hour, the power cost would be $3.65 per gross irrigated hectare.

Construction costs of tube wells per unit of capacity diminish with increasing well capacity. Compared with larger wells, the maximum cost should be for wells pumping 0.03 m^3/sec. Assuming that the cost is $10,000 per well, the total cost for 170,000 wells would be $1.7 billion. Amortized over 10 years at 8 percent, the annual costs of well construction would be roughly $14.00 per gross irrigated hectare. To these fuel and capital costs should be added the cost of land for the tube wells and the drainage and conveyance channels, the cost of constructing these channels, and the labor costs for maintenance and operation of the system. With our present information we are unable to estimate these costs, but we believe they should be less than $15 per year per gross irrigated hectare.

The total annual costs would thus be about $40 to $45 per gross irrigated hectare. With adequate water management and proper use of fertilizers and other inputs, it would be possible to obtain high productivity from high-yielding crop varieties on the irrigated fields, in contrast to the present yields from traditional varieties, which must be used on unirrigated lands. The gross value of cereal crops would be of the order of $500 per hectare, ten times the annual costs of irrigation water supplies.

Of equal importance would be the increased food production from the newly irrigated lands. For the entire Ganges Plain, the storage of monsoon waters along tributaries by the pumping scheme we have proposed would provide a basis for an increase in production of 55×10^6 metric tons per year. All storage methods combined, together with increased kharif irrigation from canals, would give more than 110×10^6 tons above present production, enough by itself to provide a greatly improved diet for 400 million people.

In Table 1 we estimate that 6×10^6 ha-m would be used for irrigation during the kharif season of monsoon rainfall and high river flows. The necessity for irrigation in this season is due both to the large variation from year to year in total monsoon rainfall and to the intraseasonal irregularity of the rainfall. In many areas, water supplies for monsoon irrigation could be obtained by construction of barrages across Ganges tributaries, which will divert waters into systems of canals, distributaries, and water courses. From 35 to 50 percent of this water will seep into the ground and can be used for well irrigation during the dry season. Thus, the possibilities for total underground storage are much larger than our estimates of the storage that can be obtained by pumping out the aquifers along tributaries. The total potential irrigation in the Ganges Plain may be limited by the area of irrigable land rather than the water supply.

Need for Further Investigation

The choice between systems for storage of underground water will vary from region to region, and possibly with the stage of development of the integrated system of surface and groundwater irrigation. Further detailed field investigation and systematic analysis are required to determine the choice and sequence of investments for irrigation. Among the factors which should be considered are: the effects of sediment transportation and deposition, which might reduce infiltration rates from the rivers, the possible hazards of subsidence resulting from lowering the water table, and possible ecological effects. Special attention should be paid to design and construction of irrigation projects that are compatible with the long-range objectives of storing monsoon waters and maintaining the present volume of flow during the dry season. Projects that are incompatible with these objectives should not be initiated.

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   The average amount of water evaporating from the water table is probably between 2 and 3 cm. A reduction of 2 cm over an area of 40×10^6 ha might be obtained if the average depth to the water table were lowered by a few meters. This should not seriously interfere with the seepage of groundwaters into the rivers, which is the source of much of the river flows during the dry season. We estimate that construction of a sufficient number of low bunds at right angles to the flow lines in uncultivated areas might increase rainfall infiltration by 10 percent or 0.7×10^6 ha-m.

Dasheen leaf [Courtesy U.S. Department of Agriculture, Washington, D.C.] →

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Land Use for Agricultural Production: Agricultural Land Use and Soil Erosion

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The purpose of this paper is to describe briefly the present agricultural land use pattern in the U.S. and to indicate some of the more important agronomic factors influencing agricultural land use changes and potential soil erosion.

Land Use in the United States

The land surface of the United States is a semi-fixed quantity standing at 2,313 million acres. About 42 million acres are covered by water, bringing the total land surface to about 2,271 million acres [1]. In 1969 about 80 per cent of the total land area was used for direct agricultural production, including forestry and grazing. About half of the other 20 per cent was used for urban development, transportation, public installations, wildlife refuges, and recreation facilities. The remainder was desert, swamp, tundra, or other land of limited use [2, 3]. During the period 1959 through 1969, approximately 2.2 million acres of rural land were shifted each year to non-farm uses. These uses included urban development (730,000 acres), airports and highways (130,000 acres), reservoirs and flood control (300,000 acres), recreation and wilderness areas, parks and wildlife refuges (1,000,000 acres) (excluding Alaska) [2, 3].

In 1958 and again in 1967, the Soil Conservation Service and cooperating agencies made a national inventory of the soil and water conservation needs [3]. In the 1958 inventory, a soil survey was made of selected sample areas of all rural land, excluding non-cropped federal land. These data were expanded, using appropriate statistical procedures, to estimate the acreage of different land uses in each county. All land uses were estimated by field inspection of sample areas. This was called a Conservation Needs Inventory (CNI). Of the 1,438 million acres in the 1967 CNI in the United States, approximately 30 per cent was estimated to be cropland, 34 per cent permanent grassland, and 32 percent forest land. Other land uses, including farmsteads, farm roads, and miscellaneous uses, amounted to 4 per cent.

Soil mapping units mapped in the soil survey were classified and grouped into eight general land capability classes that were defined on the basis of the degree of soil limitation for growing field crops. The capability grouping reflects potentialities and limitations for sustained production of common field crops without specialized site conditioning. Class I land is suitable for the continuous cultivation of most agricultural crops without special water and erosion control measures. Class II and Class III land are suitable for regular and fairly intensive cultivation of most field crops if conservation treatments are applied. These practices include water conservation and erosion control measures and, in addition, ade-

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quate fertilization. Class IV land is marginal for growing most field crops. Soil mapping units grouped into Land Classes V, VI, VII, and VIII generally are not suitable for growing most field crops, but are suitable for other, less intensive uses, such as permanent pasture, woodland, and some horticultural crops [4].

The acreage of land by individual land classes is shown in Table 1.

TABLE 1.

Conservation Needs Inventory Acreage in Land Use Capability Classes, U.S. 1967

Capability Class	Acreage Millions of Acres		Percent of Inventory Area	
I	47		3	
II	287	631	20	44
III	297		21	
IV	180		13	
V	32		2	
VI	278	627	19	
VII	287		20	41
VIII	30		2	

The land (631 million acres) suitable for cultivation (land Classes I, II, III) is approximately equal to the amount of land unsuited to cultivation, (Land Classes V through VIII).

The 1967 Conservation Needs Inventory determined the major types of land use and the acreage in each of the land classes. Cropland, pasture and range land, forest land and other land use acreage by land class groups is shown in Table 2 [3].

Fifty-eight per cent of the land suitable for crop land (Classes I, II, III) was used as cropland. Thirty-eight per cent was used for pasture and woodland. This potential cropland constitutes a reserve that could have been converted to crop production on demand. Soil erosion losses would be expected to be much less on most of the class I, II, and III land used for pasture and woodland than if they were used for tilled crop land. Twenty-five million acres of the land in classes V through VII were unfortunately in cropland. This land is poorly suited to crop production. On much of this land, erosion control practices probably are not feasible. Some shifting of this land to other uses has occurred. In 1949 the estimated land used as cropland in the U.S. included 39 million acres of land in Classes V through VIII. Some of this land has been shifted to pasture and trees by 1958, thus decreasing its erosion potential. Twenty-eight per cent of the Class IV land was being used for cropland in 1967. There were 47 million acres of Class I land in the U.S. in 1967; only

TABLE 2.

Land Use by Land Capability Class in the 1967 Conservation Needs Inventory

Land Classes	Millions of acres	Per cent of total acreage within class groups
I, II, III		
Land Use		
Cropland	365	58
Pasture & Range	117	18
Forest	126	20
Miscellaneous Use	23	4
Total	631	
IV		
Land Use		
Cropland	50	28
Pasture or Forest and Miscellaneous	130	72
Total	180	
V, VI, VII, VIII		
Land Use		
Cropland	25	4
Pasture or Forest	577	92
Other land uses	25	4
Total	627	

thirty-six million acres, or 77 per cent, were being used for cropland. Eleven million acres of the Class I land suitable for continuous row crops were used for pasture and woodland and other uses [3].

These data appear to indicate that land users generally have done a fair to good job of matching the use of the land to the land use capability class of the soils. However, since 11 million acres of the Class I land, and 243 million acres of Class II and III land were used principally for pasture and forest in 1967, one might conclude that there was sub-optimal use of much of the land with respect to its physical capability. The fact that 25 million acres of the Class V through VIII land were used as cropland also indicates that much of the land was not matched to its most suitable use in 1967.

There are many possible reasons that explain partially the matching or mis-matching of crops to the conservation and productive potential of the land. Some of the most important factors that have influenced land use are the physical and chemical characteristics of the soils and the configuration of the landscapes. Although social, institutional, and economic factors also have influenced land use, they will not be considered within the scope of this discussion.

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Soils and landscape features have played a dominant role in influencing the distribution of otherwise climatically adapted crops. Three physical characteristics of land influence its use for crop production; 1) the soils, 2) their pattern of distribution on the landscape, and 3) the features of the landscape.

Some of the soils in land use capability classes II and III, even though suitable for cropland, have relatively low and highly variable crop yields due to a variety of factors. They may be excessively wet, as is the case of the soils included in sub-classes IIs, IIIs, IIc, and IIIc. It may or may not become economically feasible in the future to modify these conditions by drainage or irrigation. Soils in sub-classes IIe, IIIe, and IVe have sloping topography and are subject to excessive erosion unless adequately protected by erosion control practices. The economic feasibility of such practices is strongly dependent on the economic value of the crops to be grown and societal incentives.

Since most of the Class IV, V, VI, VII and VIII soils are poorly suited to tilled crops, land users have tended to shift this land to pasture and woodland. The small pockets of Class I, II, or III soils that are intimately associated with higher classification soils were also shifted to pasture and woodland because those areas were too small to be farmed with large farm machinery.

Where relatively large acreages of Class I, II, or III land are found in natural bodies along narrow stream valleys, farm property lines dissect these areas into small irregularly shaped units that are ill-suited to mechanized farming. Also some potential crop land (Class I-III) that is found along streams may be flooded frequently and hence it would be too risky for use with tilled crops.

Tabor [5] found in a study of individual tracts of land in 3 soil associations in Maury County, Tennessee, that many of the highly productive soil mapping units suitable for intensive row cropping were small in size, irregularly shaped and occurred in a distribution pattern that made it difficult to combine them with other similar soil mapping units into large fields for efficient use of large farm machinery. Using a 2-acre minimum field size, cropping systems to keep the soil loss within tolerance limits, and certain field shape restrictions, he found that much of the cropland had to be shifted to pasture or idle land with greatly reduced net income. The average net income for the 3 soil associations after imposing these restrictions was 52 per cent less than the net income without these restrictions.

Oschwald [6] studied the effect of soil mapping unit distribution patterns on crop sequence suitability in Iowa. He found that Sharpsburg, 2 to 5 per cent slopes, was suitable for continuous corn with suitable erosion and water control practices when considered alone, but only 40 per cent could be in continuous corn if the soil pattern in which it occurred were considered. In another soil pattern, Colo-Gravity, 2 to 5 per cent slopes, the combined effect of stream dissection and of occurrence with predominately more sloping soils resulted in less than 3 per cent continuous corn suitability for this association.

Smith [7] using CNI data (1958) found that approximately 6 million acres of Class I-III land in the Tennessee Valley were idle, in pasture or in woodland. This represented over 50% of the Class I-III land in the Tennessee Valley. Boxley and Blass [8] associated this extensive land use to the occurrence of part-time farms. For example, farmers shifted their land to pastures for a cow-calf system of beef cattle farming which was compatible with their off-farm work.

Small areas of productive soils in Land Classes I and II are well suited to some high labor-intensive crops such as burley tobacco. Usually small acreages of such crops per farm utilize these small areas of productive land very efficiently. However, shifts of large acreage to this type of row crop culture in the future is unlikely.

These soil and landscape relationships have many counterparts in many other regions of the U.S. Hence, they appear to be a major factor in determining the use of land for tilled crop production where large fields are required for the efficient use of mechanized equipment. Much of the eastern U.S., especially the Appalachian region, the Delta states and the Piedmont regions of the Southeast, and to a much lesser degree the corn belt, and the Plains states, have a soil distribution pattern and landscape features that make many areas poorly adapted to the use of the large mechanized planting and harvesting equipment. A land use pattern where large acreages of Land Classes II and III are used for pasture and woodland with appropriate management has the potential for greater reductions of soil erosion losses than if they were used for cropland.

The soil distribution pattern of the U.S. has been greatly influenced by the natural erosion and deposition which have influenced the present land use pattern. The young alluvial soils and loess and glacial till-derived soils which comprise much of our productive cropland are the result of natural processes of erosion and sedimentation. The slow evolutionary geologic erosion and sedimentation process has not

been a despoiler of the environment; it has played quite the opposite role. However, when the rate of erosion and sedimentation processes are greatly accelerated, erosion of upland and terrace soils exposes clayey horizons, fragipans, or other undesirable subsurface horizons that result in lower moisture supplying capacity. Where yields of tilled crops are greatly reduced, land users have shifted much of this land to permanent pasture or woodland, and soil erosion has been arrested.

Cropping Systems in Relation to Soil Resources

Of the total agricultural land in the U.S., the cropland harvested has a greater potential for soil erosion than pasture or woodland since during a portion of the year, the land usually is not protected with actively-growing vegetation. Numerous measurements of soil erosion from field plots leave no doubt that cultivated fields can be a major contributor to the erosion-sediment problem.

Fully 90 per cent of the total crop acreage harvested is accounted for by corn, grain sorghum, wheat, oats, barley, cotton, soybeans, and hay crops. From 1930 to 1970 the harvested cropland acreage in the continental U.S. has been steadily declining. The acreage of crop land harvested declined from approximately 360 million acres in 1930 to 285 million in 1970, about 21 per cent [9].

Significant regional changes in harvested cropland have occurred in the last two decades. In some regions acreage of harvested crops has declined, while in others it has increased. From 1940 to 1965, land in harvested crops declined 54 per cent in the Northeastern states, 33 percent in the Appalachian region, and 26 per cent in the Delta states. During the same period land in harvested crop acreage increased 4 per cent in the Corn Belt, 1 per cent in the northern Plains states, 29 per cent in the Mountain states and 8 per cent in the Pacific states [10].

The eastern U.S. has experienced a greater decline in harvested cropland than any other region of the country. Much of this is due to the soil patterns and landscape features which are undesirable for mechanized farming and effective erosion control. The decline is also partly due to the past accelerated soil erosion in the area. Much of this area, which formerly was in row crops, is moderately to severely-eroded and produces low and often uneconomical yields of tilled crops. It has been planted to adapted perennial grasses and trees and accelerated erosion has been arrested. The rapid urbanization of this region also has occupied some of the cropland. Much of the increase in harvested crop land acreage in the Mountain and Pacific states has been on nearly level irrigated land with a low erosion potential. [9].

The present regional land use pattern in the U.S. for the major harvested crops is indicative of the appropriate matching of these crops and the accompanying technology to the soils, climate, and water resources of the different regions. Within the more humid regions of the U.S. the climatic patterns, the soils, and the landscape features are dominant factors influencing crop distribution and land use. In the arid regions, availability of adequate quality and amounts of irrigation water is an additional dominant factor.

Most of the acreage of corn is in the Corn Belt states, where it is well suited. Soybeans, traditionally a Corn Belt crop, have expanded into the southeastern states particularly in the Mississippi Delta. Grain sorghum production is concentrated in the southern Plains states, where in recent decades it has replaced some of the corn acreage. Some of the acreage of grain sorghum has entered the western Corn Belt. To a lesser extent, grain sorghum is grown in the irrigated regions of the southwest. Cotton acreage has declined in the Piedmont areas of the southeast and has shifted to the more gently sloping land of the Coastal Plain and Delta regions. It has also increased in the irrigated areas of the southern Plains states, the Southwest and California. [9].

Small grain acreage is concentrated in the Plains states. Cotton production, which requires a long growing season, is restricted to the southern and southwestern U.S. Soybeans, grain sorghum, corn, small grain and many hay crops, using locally adapted cultivars, have a rather wide range of adaptation. These crops generally are being produced in regions and on soils within regions where they have the greatest competitive advantage.

As acreage used for crops has decreased and harvested crop acreage has shifted among and within regions, crop yields have increased dramatically. From 1950 to 1971, the crop production per acre increased about 60 per cent [2]. With the increased crop yields per acre, the area needed to produce a given crop production volume has decreased dramatically; this is perhaps one of the most significant factors influencing land use in the last three decades.

Barrons [9] has computed the acreage that would be required to produce the total production of recent years (1968-70) at the yield level existing before present technology and methods of crop production came into full play (1938-40). The U.S. acreage of 17 major harvested crops, saved annually for alternative uses during 1968-70 as a result of increase in yield of these crops since 1938-40, is

approximately 290 million acres. This is approximately equal to the total 1970 acreage of cropland in the continental U.S., an area equal to all the land in the U.S. east of the Mississippi River and south of the Ohio River. If we were now obtaining the crop yields that prevailed in the late 1930's, this greater required acreage would be on the more erodible rolling topography. Thus by increasing the yield per acre, some of the cropland that would be subjected to soil erosion can be shifted to permanent pasture and woodland, where the potential for soil erosion is much less.

The phenomenal increase in crop yields is due to no single cause, but to the development and application of a systems approach to land management, where multiple limiting factors are considered simultaneously. Adding one or more production factors when others are limiting can be counterproductive. Crop response to one or more factors of production is usually dependent on the level of other factors. The sum of the independent yield effects of two or more added deficient factors of production is often times less than the yield effects when added together. This is generally called the principle of interaction. The use and application of this systems approach especially in the use of increased and more efficient amounts of management inputs for crop production account for the dramatic upsurge in crop yields in the past three decades.

Even though the systems approach to land management has not been applied universally to all our farm land, enough has been applied to increase crop yields. The following production technology has been incorporated in land management systems and applied widely to crop production throughout this country.

Crops have not only been matched to the major soil and climatic regions but to much of the land on individual farms within a given soil and climatic region. Crops have been matched to the soils and landscape features for which they are best suited using modern mechanization and other technology. In the more humid regions of the U.S., tilled crops usually have been allocated to the well-drained and moderately well-drained soils with high moisture-supplying capacity and with nearly level or gently sloping topography, for high and more certain yield and permissible soil erosion loss. Small grain and other cool-season crops are usually allocated to the more droughty soils and sloping topography, since moisture is rarely a limiting factor during their growing season. Furthermore, since they are close-seeded crops the erosion hazard on slopes is less serious than with row crops. Pasture and hay crops also are adapted to and compatible with a wide range of soil drainage and more sloping topography, although these crops are usually less profitable than tilled crops on the more productive soils. They often are allocated to poorly or somewhat poorly drained soils, or to droughty soils on rolling to steep topography. Being close-seeded crops, and usually perennial, the erosion hazard on rolling and steep topography is much less serious than with row crops or small grains. Cropping systems also have been matched not only to the land but to the livestock system and to other resources, including the management ability of the farmer.

Appropriate matching of crops to the land on individual farms and the selection of appropriate water and erosion control measures have been greatly aided in the past decade by the widespread availability and use of detailed soil survey maps, and by the development and use of the Universal Soil Loss Prediction Equation. As of June, 1972, the Soil Conservation Service and cooperating agencies have reported detailed soil survey mapping on a total of 774 million acres, and 41 million acres of reconnaissance soil surveys. In addition, exploratory soil survey mapping has been completed on 274 million acres in Alaska. Detailed soil maps and accompanying soils information are widely accepted and used by professional farm managers and agricultural workers for farm and ranch planning [11].

The Universal Soil Loss Prediction Equation is being used for planning cropping systems and water and erosion control measures in the 36 states east of the continental divide. There is also some use of the soil loss equation in the states west of the continental divide, particularly Utah and Idaho. The states of Montana, Wyoming, Colorado, and New Mexico are using the equation in the portion of the states east of the divide. The USLPE has been well accepted by soil conservationists and some farmers in the states where it is being used. The best example of impact of the soil-loss equation is the new Iowa Soil Conservation Act-House File 73. The soil-loss equation is used to estimate the soil loss on areas where soil erosion has been declared a nuisance. Thus it has become a valuable tool for implementation of the law [12].

Few farmers in the U.S. are following a rigid crop rotation. Most farms have diverse soil and topographic patterns. If rotation were practiced on all the land, some row crops would be grown on soils for which they are not well-suited for either production or control of soil erosion. By concentrating the row crops on gently sloping or nearly level productive lands and continuously cropping them,

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higher yields and less soil erosion can result on the farm as a whole.

In the Midwest, on nearly level and gently sloping topography, corn is seldom rotated. Before World War II a 2-year rotation of corn-oats-clover was used and an average yield of about 38 bushels of corn per acre was obtained. Instead of planting 33 of each 100 acres in corn and obtaining a total yield of 1250 bushels, now the farmer plants the whole 100 acres in corn and harvests 10,000. This shift to more continuous cropping on the potentially more productive soils occurring on less gently sloping topography has occurred also with other row crops in other regions of the U.S.

Multiple cropping is defined as the harvesting of one or more crops from the same land area during a given period of time, usually one year. Increased total yield per unit area can be obtained from harvesting more than one crop during a growing period. Multiple cropping is a practice widely used with vegetable crops, and it is gaining acceptance with other crops. With adequate length of growing season corn silage can be double-cropped with small grains for forage. Soybeans are double-cropped with small grains. These practices have not only provided a method for increasing the total yield per acre, but they may decrease erosion because live vegetation is on the land a greater portion of the year.

In the past three decades strip-cropping, terraces, contour farming, minimum tillage systems, and many other soil erosion control measures have been adopted and used on millions of acres of cropland. These measures have not only aided land users in reducing soil erosion but also have contributed to maintaining soil productivity and reduced off-site sediment damage. However, implementation of erosion control measures on cropland is far from being completed [3]. For example, only 36 per cent of the cropland, as reported in the Conservation Needs Inventory, has been adequately treated with soil and water conservation practices and measures to hold soil losses to an acceptable level.

From 1950 to 1970, commercial fertilizer use more than doubled, from 18.0 to 39.2 million tons [13]. During this period, fertilizer efficiency has also increased with increasing use of soil tests, and the amount of fertilizer applied has been in a more balanced relationship to the available levels in the soil and to the specific requirements of a crop and its predicted response. Farmers also have adjusted the amounts added according to the available moisture supplying capacity of the soil, or in case of irrigated soils, they have adjusted the amounts of fertilizer in relation to the supply of irrigation water. Much land formerly planted to forage legumes in order to supply nitrogen for corn and other cultivated crops is no longer used in this way since most of the nitrogen is obtained from commercial N.

Increased use of fertilizer, along with other inputs, has greatly increased the yield and vigor of vegetative growth of crops and hence has increased protective capability of the crop against soil erosion loss. Greater root growth and the return to the soil of a greater volume of crop residues are both important considerations in protecting soil from erosion losses.

Farm mechanization is necessary for high total productivity in the U.S. because of scarcity of farm labor. Mechanization, particularly of tilled crops, has shifted land use to farms with more level topography and a soil pattern that is rather homogeneous. Large planting and harvesting machinery can be operated more efficiently in uniform soil and topographic situations. Mechanization has been a dominant factor in much of the shift from tilled crops to pasture or vice versa. Mechanization also increases yields on a given land area because planting, harvesting, and crop protection operations are performed at the right time, thus increasing crop yields.

Many superior cultivars of major crops have been developed in the past three decades. For example, they are high yielding and more resistant to lodging at high rates of fertilization and plant population than previously available strains. The widespread availability and use of these superior cultivars have been major factors in increased yields in the U.S. The control of disease organisms, insects, and weed infestations by using effective pest control systems has greatly influenced crop yields and land use patterns.

Major modification of the soil-water regime of potential cropland has been carried out in the last three decades by 1) draining excessively wet land, 2) irrigating drylands, and 3) decreasing bottomland flooding. The 1959 Census of Agriculture shows that nearly 102 million acres in 39 states are contained in more than 8400 drainage enterprises with areas over 500 acres in size. Within these enterprises, drainage modifications have been made on about 92 million acres. By 1967 about 39 million acres not covered by the Census had been drained by individual land owners. In 1972 the Soil Conservation Service estimated that 130 million acres, or about one-third of all crop land, is drained artificially. Many farmers have shifted tilled crops from rolling land to drained land and thus have reduced the erosion potential on the upland and terrace soils. However, some land areas that have been drained

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have proved to be undesirable for cropland and it would have been a wiser decision to have left them undrained.

In the three decades from 1939 to 1969 the acreage of irrigated land in the continental United States more than doubled, increasing from just under 18.0 million acres in 1939 to 39.1 million acres in 1969, most of it in the western water resources regions. Estimates based on work by Durost and Barton [15] indicate that increases in irrigated acreage accounted for between 5 and 8 per cent of the growth in farm output between 1930 and 1960. Another indication of the impact of irrigation on agricultural output is that the 7.2 million acres of irrigated land brought into production between 1949 and 1959 were roughly equivalent in productive capacity to the 25-30 million acres taken out of agricultural production during this same period for non-farm use and by the acreage allotment.

Up through June 1972, 1,060 watershed protection and flood prevention projects had been approved for operation under Public Law 566. These projects were designed to enable farmers to shift much land in flood plains from pasture and woodland to tilled crops. Including all the land in the watershed project (upland and bottomland), there has been a net decrease in land used for row crops. Farmers have shifted tilled crops from rolling land to bottomland, thus reducing the erosion potential on the watersheds [16].

Summary

Agricultural land use has undergone many revolutionary changes in the last three decades. Most of these changes have resulted in greater yield per acre, greater total agriculture output of crops and livestock, and a steady decline in acreage of harvested crops. It appears also that the net result of these land use changes is reduced soil erosion over what it would have been if these changes had not taken place. At present, and for the next few decades at least, American agriculture has a large unused productive land potential for the production of crops. There seems little reason for concern about the nation's ability to feed itself. By increasing agricultural output and shifting some land to vegetables and cereals, the U.S. has land potential to feed many times its present population.

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ALTERNATIVES TO PESTICIDES IN SOUTHEASTERN UNITED STATES

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SUMMARY

A critical review of alternatives to the use of pesticides in agricultural practice in the Southeastern United States is presented. The methods, their stage of development and case histories are cited.

INTRODUCTION

Pest management should be predicated on the totality of knowledge of all pest control methods and the ecological impact. Effective control measures should be those which consider the long-term ecological and economic aspects. The indiscriminate use of any single control method may produce undesirable and unintended side-effects[1]. On balance, the introduction of chemicals such as pesticides to agricultural practice has been beneficial. However, not all the effects have been positive. Problems have arisen, some quite serious, which detract from the benefits[2,3]. This is attributed in a large measure to the disruptive impact on the ecosystem[4]. The benefits of pesticides have been so evident that alternatives have not been evaluated with equal vigor. All practices, whether chemical, cultural, physical, genetic or biological, must bring about the most effective, least ecologically disruptive, pest control possible. Although alternative methods are sought, it is generally conceded that pesticides will be used to control pests into the foreseeable future[5].

The objective of this review is to examine alternatives to pesticides, particularly those which offer potential or have been utilized in the Southeastern United States.

CULTURAL METHODS

Pest control methods are effective because they either directly affect the pest species or adversely modify environmental conditions necessary for its survival.

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Cultural methods are routinely utilized in agricultural practice to reduce pest-related problems. These usually involve adjusting the time or manner of performing operations for the production of crops or animals, or in improving management procedures. Examples of methods[6-10] and the target pest species include:

(*i*) *Sanitation.* Destruction of crop refuse (boll weevil, bollworm, corn borer); cleaning of field borders (weed control); disposal of wastes (fly control).

(*ii*) *Rotation.* Crop rotation (fungal spores, bacteria, mites, insects and viruses, nematodes); animal rotation (cattle tick control).

(*iii*) *Farm management.* Land bank and fallowing (cyst nematodes); strip cropping (alfalfa aphid); fertilizers (chinch bugs, weeds); time of planting (southeastern corn borer, sugar-beet nematode); pest-free seeds (weed control, wheat nematode control); destruction of volunteer plants (potato aphids); destruction of alternate hosts (wheat and apple rusts, beet leaf hoppers, sweet potato weevils); destruction of early blooms (sorghum midge); tillage (grape berry moths); crop spacing (weeds); cleaning of farm equipment (weed control); trap crops (citrus red mite); regulation of plant stands (citrus pests); selection of site (various forest insects); thinning, topping, pruning and defoliating (tobacco hornworm, mite and control of dutch elm disease).

(*iv*) *Water management.* Irrigation and flooding, (root-knot and white-tip nematodes); impoundment and improved pond management (aquatic weeds, mosquitoes, biting midges); drainage (nematodes).

The southwestern corn borer, *Diatraea grandiosella*, has slowly migrated eastward and has been reported in western Tennessee and Alabama[11]. Cultural practices which increase exposure of the larvae to the environment and predators are effective in increasing overwintering mortality. Burying, *per se*, is not detrimental to the larvae but it prevents the moths from emerging from the soil. Early planting of corn lessens damage with the primary advantage being a reduction in girdling. Generally corn planted in Tennessee before May 1 is damaged less by girdling, but infestation and lodging are not consistently reduced in all years and locations.

The pink bollworm provides a classic example of a major cotton pest that may be controlled by cultural practices. The control program includes stalk destruction and deep plowing of the residue after the crop is harvested. Two factors, overwintering as larvae and a single host plant (cotton), make this pest highly susceptible to this practice. When cultural measures are used in conjunction with good agronomic practices the pink bollworm population may be reduced to low levels. Often damaging bollworm populations do not develop the following year.

Attacking the boll weevil and pink bollworm during the fall of the year is a biologically and operationally sound practice aimed at destruction of the diapausing populations. Only bollworms that are in diapause are able to survive the winter. This is the weakest link in the life cycle. A factor in the success of this method is that these two cotton pests do not develop large populations on wild or alternate host plants[12]. The great majority of the diapausing boll weevils leave the cotton fields for hibernation sites during the harvest period of late September and October. The adult requires a feeding period of 1 to 3 weeks to accumulate sufficient fat reserve to attain

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practice is defoliation of the cotton plants. This eliminates squares and young bolls necessary for the development of diapausing populations. The next most important practice is to harvest the crop as quickly as possible and then destroy the stalks. Destruction of plant residues, crop rotation, utilization of high potash fertilizers etc. have been effective methods of control of cotton diseases such as anthracnose, bacterial blight, fusarium wilt, root-knot nematodes and seedling diseases[13].

Cultural methods which control weeds in cotton fields are important. Production techniques which promote rapid crop emergence and growth tend to control weeds by shading. Some cultural practices permit the use of herbicide for weed control on alternate crops in a more effective manner than with a single crop. For example cocklebur is very difficult to control in cotton fields but relatively easy to control in corn fields. Hence, rotation and eradication are complementary. Disking or plowing six to eight times during a growing season effectively reduces Johnson grass rhizomes prior to the succeeding growing season. Similarly, plowing or disking every four weeks for two successive growing seasons has been reported to essentially eradicate nutsedge[14].

PHYSICAL AND MECHANICAL METHODS

Preventive and corrective physical and mechanical methods differ from cultural methods since they are intended specifically to control pests and are not routine agricultural practices. Their effectiveness lies in the fact that all biological species exhibit thresholds of tolerance with regard to temperature, humidity, sound, and response to various regions of the electromagnetic spectrum. The possibilities for control techniques involving the spectrum of radiant energy and devices such as light traps are especially promising[15,16].

Temperature is utilized in the control of soil-borne diseases caused by bacteria, viruses, fungi and nematodes[6]. Fire has been found to be an effective method of control of the alfalfa weevil, *Hypera postica*[17]. Seeds are often protected by storage at low temperatures (4–10°C) since most grain-infesting insects are inactive at these temperatures. Temperature may affect the susceptibility of host plants to virus infection, the time required for development of symptoms, and the degree of damage. The principle also applies in those cases where the majority of plants in a vegetatively propagated clone are infected[18].

A hot-water treatment, alone or in combination with a nematocidal dip, is used to treat plants contaminated with ectoparasitic nematodes such as *Hemicycliophora* sp. or *Criconemoides* sp. These pests are difficult to dislodge by mechanical means because their long stylets are inserted into the plant cells. Endoparasitic nematodes present with plant tissues or enclosed within the protective layers of plant parts require a penetrating chemical or physical agent to affect a kill. Heat is most commonly used. Externally applied heat is absorbed by the plant propagule and ultimately penetrates to reach the pathogens. Heat treatment is effective when the

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temperature level of nematode sensitivity is below that of the plant-tissue sensitivity. Examples of recommended temperature–time treatments found useful for control of parasitic nematodes include: Easter lily bulbs with spring crimp nematode, *Aphelenchoides fragariae*, 1 h at 44°C in a water and formalin bath; citrus rootstock with burrowing nematode, *Radopholus similis*, 10 min at 50°C; and grape rootings with root-knot nematodes, 30 min at 47.8°C, 10 min at 49°C, 5 min at 51.6°C, or 3 min at 53°C (refs. 9, 17).

Light traps employing ultraviolet or blacklight lamps are being evaluated to determine their effectiveness for attracting moths[19]. In one 113-square mile area in North Carolina, 370 traps were estimated to have exterminated 50 to 60% of the adult tobacco hornworm moths in one growing season. A trap density of three per square mile in combination with stalk cutting and insecticide treatment to prevent late season breeding of hornworms, further reduced infestation by about 80%. This moth reduction was measured at the center of the test area during the second year. About 20 times as many males as females were captured demonstrating the potential for decreasing mating incidence.

Other examples of blacklight traps for insect control include the protection of cabbage from the cabbage looper, *Trichoplusia ni*, and of celery from the celery looper, *Anagrapha falcifera*[8]. The European corn borer and the cotton bollworm can be significantly reduced by light traps if population pressure is not excessive. Damage to tomato fruit and foliage resulting from the attack of tobacco and tomato hornworms can be minimized[8]. The increase in yield of cucumbers from plants protected by light traps has been especially encouraging; populations of the striped and spotted cucumber beetle were reduced and the transmission of bacterial wilt was minimized. The benefit of the light trap is that it eliminates the need for chemical applications in those climatic areas where light attraction is consistently effective. Light traps may be used to attract moths and bring them into contact with chemosterilants.

Not all moths and flying beetles are attracted to blacklight sources. This limits the application of this control method. Further, the practice requires electrical power which may not always be available. The advantages are: no residues are left on crops; moth emergence is detected and this provides a means for timing of control measures; attraction occurs irrespective of the physical condition of the field; the method may be integrated with other control approaches (*e.g.* post season stalk cutting in tobacco)[16,19]; and it is low in operating cost.

RESISTANT VARIETIES

Plants or animals that exhibit less damage or infestation by a pest (disease, nematode or insect) than others under comparable conditions in the field are considered to be resistant. Selection and improvement results in a resistant variety which becomes an integral part of the pest-management program. One of the most important contributions of agricultural programs of the pre-DDT era was the development of resistant varieties. This method of reducing pest damage has been used extensively since the turn of the century. Originally the case for use of naturally resistant plants

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was economic; it added little or nothing to the grower's cost of production. Pollution control is currently a consideration.

With crops such as alfalfa, small grains and tobacco, it is the availability of resistant varieties which makes the difference between profit or loss. In other cases the resistance factor is even more important in that it makes culture of the crop possible. Stem rot of peanuts, rusts and smuts of cereals; anthracnose of watermelon; and fusarium wilt, mosaic, black shank, and black-root rot of tobacco are examples of the diseases which are primarily controlled by planting resistant varieties. Approximately 75% of the total acreage in agriculture production in the United States is currently planted with resistant varieties[10]. Varietal resistance to insects and other pests is classified into three broad categories: *Preference* (for oviposition, food or shelter), *antibiosis* (adverse effect of plant on biology of insect) and *tolerance* (repair, recovery or ability to withstand infestation)[20]. Secondary plant substances (terpenes, quinones, alkaloids) contribute to preference and antibiosis resistance mechanisms against insects and diseases[21].

A classical example of the use of plant genetics is the control of grape *Phylloxera* in Europe over the past 90 years. Highly resistant American varieties saved European viticulture[5]. A search for plants resistant to insects was conducted in California over a 10-year period beginning in 1881 (ref. 20). By the turn of the century, many programs were underway. These included: mildew resistance of grapes in France; late blight of potatoes in several European countries; rust resistance in wheat in Australia, England and the United States; and wilt resistance in flax, cotton, watermelon and cowpeas in the United States. These and many other programs are still being pursued actively today[22,23]. Each year new resistant varieties are introduced. Current research is being directed toward incorporating multiple pest resistance into crop varieties. Development and use of resistant host plants is one of the most effective methods of economic pest management in agricultural ecosystems.

A bacterial disease known as Granville became a limiting factor in production of flue-cured tobacco in North Carolina following the turn of the century. Losses in Granville County alone during the period 1920 to 1940 were estimated to be 30–40 million dollars. Intensive research to develop wilt-resistant tobacco was initiated in 1935. This effort culminated in the introduction in 1944 of a resistant tobacco variety of acceptable quality. Program cost was about $150,000. By 1948, the value of tobacco grown in the area of Granville was estimated to be $2,000,000. By 1964, 416,000 acres were devoted to the tobacco crop in North Carolina with an estimated value of $520,000,000. Approximately 95% of this acreage was planted in varieties which not only incorporated resistance to Granville wilt, but also to black shank. It is estimated that if resistant varieties were not available the yield would have been reduced to less than one-fourth[22,24]. These major tobacco diseases involve soil-borne pathogens. Effective chemical controls were not available and the effectiveness or practicality of other approaches, including rotation and related cultural practices, would have been limited.

Varietal resistance as a means of controlling cotton pests has generally been ignored until recently. Screening of available germplasm has recently proved to be

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highly rewarding. The possibility of controlling *Heliothis* sp. and other lepidopetrous pests by incorporating high levels of gossypol and other pigments into commercial varieties appears to be especially promising. Plants having a gossypol content of 1.5% or more cause both larval mortality and inhibition in development of *Heliothis* larvae. Such levels have been attained in several lines. High gossypol content is undesirable in cotton seed because of its toxicity to non-ruminant animals. Considerable effort has been devoted to incorporating characteristics of low gossypol content into commercial varieties. This illustrates the necessity for a cooperative approach in developing varieties of cotton[12].

The spread of the boll weevil, *Anthonomus grandis*, throughout the Cotton Belt at the beginning of this century brought marked changes in the kind of cotton plant grown. The late, vigorous, long-staple upland varieties were rapidly replaced by early-maturing, short-staple types which were less susceptible to damage because of their shorter exposure period and thicker carpel walls.

Knipling[5] estimated in 1971 that $75,000,000 was being expended annually for control of the boll weevil. In spite of this expenditure, control is far from complete and the annual loss is estimated at $200,000,000. Indications of the weevil developing resistance to insecticides renewed interest in the development of resistant types. The U.S. Cotton Boll Weevil Research Laboratory was established in 1962 at State College, Miss., with the objective of finding new approaches to boll weevil control or eradication with less emphasis on use of insecticides.

Genetic factors contribute to resistance of cotton to the boll weevil. In the frego bract mutant type, the normally adherent bracts become flared and twisted. The frego types are less attractive for oviposition[25] and readily permit penetration of insecticides. Boll weevil oviposition suppression factors, attractants, feeding stimulants and repellents have also been found to be associated with resistance in cotton[26].

Discovery in 1954 of nematodes attacking soybeans in North Carolina was the first report of this pest outside the Orient[27]. Crop damage posed a threat to the United States soybean industry. Control of the soybean cyst nematodes has been difficult and multiple approaches have been necessary. Application of chemicals to the soil has not been economically feasible. Crop rotation of 2 to 3 years is effective, but results in limited production. Federal and state quarantines have been only partially successful. In 1957, some 2,800 soybeans varieties were screened for nematode resistance in heavily infested fields. Four varieties were found on which the nematode did not reproduce. The desirable characteristic of resistance was transferred to a commercial variety developed cooperatively by the Agricultural Research Service and the Agricultural Experiment Stations of Arkansas, Missouri, North Carolina, Tennessee and Virginia[27].

Disease-resistant vegetable varieties are especially noteworthy. A vegetable grower in the Southeastern States, by proper selection of such varieties, can now reduce the damage caused by such destructive diseases as fusarium wilt of cabbage, tomato and watermelon; common mosaic of beans; celery leaf blights; spinach blight, cucumber scab; and many others. In many cases, the farmer will not sacrifice the quality or productivity of his crop through use of a resistant variety[28].

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Heliothis zea is adapted to feed on a wide range of hosts and has been given common names associated with the crop attacked, *e.g.*, the corn earworm, the cotton bollworm, and the tomato fruitworm. The literature is extensive. Variation in earworm damage has been ascribed to variety, planting dates, spacings, date of maturity, soil fertility, concentration of feeding stimulant and nitrogen balance. Varietal differences have commonly been associated with husk characteristics, either extension or tightness. However, chemical differences also appear to be involved. The effect of either husk extension or husk tightness are explicable from knowledge concerning the feeding habits and cannibalistic tendencies of earworm. Either husk extension or tightness or their combination may ensure minimum damage to the developing grain, but have little or no effect on population dynamics, and therefore, represent a special case of tolerance rather than one of antibiosis[26]. Extensive research is needed to develop resistance (antibiosis) to leaf feeders.

The greatest forest disease resistance research is presently concentrated on the fusiform rust of southern pines. Agencies, both governmental and private, are engaged[29]. In North Carolina, a "rust nursery" approach is being used for mass screening of known seed sources of southern pines. This approach also permits estimation of the heritability of resistance in a natural population of southern and loblolly pine. Since 1954, a tree-improvement program has been underway in Florida. This involves screening of select slash pines for resistance to fusiform rust. Selection and field testing of slash and loblolly pines of one parent and controlled progeny are being studied for their resistance.

BIOLOGICAL AGENTS

Biological control involves the suppression of the reproductive potential of organisms through the actions of parasites, predators, or pathogens to restrict pest population at a lower average density than would occur if these were absent[3]. The interrelationships and differences between biological and chemical control are illustrated by the experience of the citrus industry in California. It once suffered a massive infestation of a mealy bug, cottony cushion-scale, *Icerya purchasi*, introduced from Australia on acacia in 1868. Two Australian ladybird beetles, *Rodolia cardinalis* and *Cryptolaemus* sp. provided the necessary predator–prey regulation. They reduced the mealy bug populations to levels at which they no longer constituted a major pest infestation. Unfortunately, cottony cushion-scale again reached major levels when extensive applications of DDT to citrus eliminated the vedalia ladybird[30]. This example of pest recurrence emphasizes an inherent risk in pesticide use. A catastrophic effect on the natural regulatory mechanisms may occur. While chemicals may temporarily diminish the numbers of a particular pest, they may also reduce its natural enemies. Subsequently, a population explosion of pests can occur before its natural enemies are able to recover.

Insects, like animals, suffer from disease attacks[31]. Under favorable conditions a disease may reach epidemic proportions for an insect species. Within a few days or weeks, it may reduce the species from a point of great abundance to one of scarcity.

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Insect diseases may be caused by protozoa, fungi, viruses and bacteria. During the last two decades, there has been an increasing awareness of the great potential of insect diseases as control agents. About 225 species of insect viruses have been isolated. Of these, the nuclear polyhedroses (107 species) and the granuloses (80 species) are candidates for effective insect control[32]. Greer[33] reported over 300 insect viruses that can be utilized for control of specific pests.

The advantages offered by microbial pest control are:

(*1*) Insect pathogens in general, and viruses in particular, are very discriminating and infect only one species or members of closely related species[34].

(2) If conditions are optimum, the introduced microbial agents may spread of their own accord, resulting in wide-spread killing of the host in natural populations.

(*3*) Microbial insecticides are biodegradable and leave no residue or build-up in the soil, as occurs with many chemical pesticides.

(*4*) Most microbial insecticides are harmless to animals and plants and may be applied in heavy doses without damaging these forms of life[31].

(*5*) Microbial pesticides are generally compatible with other pesticides.

Selected examples of arthropod pathogens and the pests successfully controlled are: nuclear polyhedrosis (bollworm–budworm complex, cabbage looper, alfalfa caterpillar) and *Bacillus thuringiensis* (many caterpillar species). Others are being evaluated[34,35].

Limitations of microbial pest control are:

(*1*) Perhaps the greatest question concerning the use of microorganisms to control insect pests has to do with the timing of application in relation to environmental conditions. The effect of high humidity on viral diseases is controversial. Viral epizootics may or may not be related to wet weather. In the laboratory, an excess of moisture often leads to the outbreak of bacterial diseases. Low humidity is generally considered a limiting factor for the spore germination, infection and subsequent sporulation of the fungus on the host. High temperature generally accelerates the course of a disease. Much remains to be learned about the optimum time to apply the microorganisms.

(*2*) It is necessary to maintain the vitality and virulence of the infecting agent especially for those microorganisms not possessing a cyst or spore stage. The possibility exists that resistant populations will develop after prolonged use of microorganisms.

(*3*) The effect of heavy applications of entomogenous microorganisms on plants and higher animals needs to be considered. There appears to be little likelihood, that microorganisms naturally pathogenic to insects could cause serious injury to animals or plants.

(*4*) A microbial insecticide can be used against one species only. Mixed formulations have as yet not been widely tested.

(*5*) Of considerable importance is the effect that pathogenic microorganisms may have upon the insect parasites and predators of a pest. Few observations have been made, but enough has been learned to suggest that close attention must be paid to this relationship whenever the artifical dissemination of microorganisms is

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contemplated. Sometimes the insect parasites and the disease are related in a complementary or supplementary fashion. This has been observed in alfalfa fields infested with caterpillars of the alfalfa butterfly, *Colias eurytheme*. In fields where the polyhedral wilt disease is present but not abundant among the caterpillars, the smaller larvae may be parasitized by *Apanteles* while the larger larvae may be killed by the polyhedral wilt disease[31].

Environmental protection necessitates curtailment of direct herbicide application to aquatic system for weed control. This is intensifying the search for alternatives. Mechanical methods are costly, usually temporary in effect, and difficult to employ, particularly in canals. Biological control offers a potential alternative for extensive areas where the cost of chemical or mechanical practices would be prohibitive.

To date, biological control of weeds has been accomplished mainly by insects; but use of mites, snails, pathogenic microorganisms, fish, ducks and geese, manatees, and parasitic higher plants are under investigation[36,37]. Caution must be exercised before any animal is introduced for weed control. In the absence of their preferred food, they may become pests of alternate plant types.

Florida red scale, *Chrysomphalus anoidum*, and purple scale, *Lepidosaphes beckii*, were until recently the two most important armored scales on citrus. Control of purple scale by the introduction of the parasite, *Aphytis lepidosaphes*, has been reported[38]. Hymenopterous parasites represent the critical control factors for the Florida red scale. *Pseudohomalopoda prima*, the parasite attacking mature female red scale, is highly important The most important parasite species appear to be *Aspidiotiphagus lounsburyi* and *Phospaltella aurantii* which attack male and second-stage female scales[39]. A special survey of Florida red scale and parasites was made between February and June 1967 on 104 groves. Parasites were identified as being either *P. prima* or *A. holoxanthus*. Parasitism by *A. holoxanthus* was very high. This parasite, which was introduced from California in 1960, appears to have much greater ability to survive adverse weather conditions than *P. prima*[40,41]. Partial to complete control has been achieved using these parasites.

Several species of parasitic insects were reared from field-collected larvae of the bollworm, *Heliothis zea* and the tobacco budworm, *H. virescens* in Mississippi[42]. The parasites belong to the families *Braconidae*, *Ichneumonidae*, and *Tachinidae*. The predominant species were two Braconids, *Microplitis croceipes* and *Cardiochiles nigriceps*. Parasites provided a high percentage of control on cranesbill, tomato, and spider flower. Observations were also reported on the effectiveness of *C. nigriceps* in controlling *H. virescens* on tobacco in areas of Florida and Georgia[43].

Parasitization by *Aphidius smithi* varies as a function of the age of pea aphid, *Acyrthosiphon pisum*. Susceptibility is highest at first instar stage. In California, this parasite has been propagated and widely released for effective control. Since 1962, this parasite has been found to be occurring in increasingly large numbers in clover and alfalfa fields in Kentucky[44].

Virus, Viron/H™, attacks only species of the genus *Heliothis* of which there are two major economic pests. One is *H. virescens*, the tobacco budworm and the other is *H. zea* commonly known as cotton bollworm. This virus has performed at

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least as well as commonly used chemical insecticides in 80 to 90% of the cases. Its greatest advantage lies in the fact that it is completely specific and is absolutely safe and non-toxic. This virus is reasonably compatible with some chemical insecticides. These can be sprayed in mixtures as long as the pH of the solution is neutral. The formulated form contains 126 billion inclusion bodies per ounce and a quart will control the bollworms on 10 acres of cotton with a light to moderate infestation. The application of this virus in practically every cotton-growing state was permitted by the Food and Drug Administration (FDA) in 1970 (ref. 33).

A biological control program for the control of bollworm and tobacco budworm was integrated into an overwintering boll weevil control program on cotton in the Mississippi Delta in 1965 (ref. 45). This program was designed to utilize biological control measures and omit chemical control during the growing season. The factors utilized in the program consisted of the naturally occurring predator–parasite complex and the application of the nuclear polyhedrosis virus. *Heliothis* control with biological agents was compared with a toxaphene–DDT–methyl parathion control using 25- to 30-acre plots. The initiation of virus applications was varied to evaluate the effectiveness of the virus against various ages of larvae. The *Heliothis* biological control program compared favorably with the insecticide program when virus application was initiated to coincide with hatches.

A study was conducted in Alabama in 1968 to determine the importance of fungus *Entomophthora* sp. as a natural control factor for field populations of the two-spotted spider mite, *Tetranychus urticae*. Studies of the distribution of this fungus revealed its presence in 14 of the 15 counties where collections were made. Average infection rate was 25% (ref. 46). Five epizootics of the pathogenic fungus were observed in two-spotted spider mite populations in Lee County, Ala. Each epizootic was characterized by a high degree of infection by *Entomophthora* sp., accompanied by a rapid decline in mite numbers.

Experiments were conducted in the state of Florida to evaluate the effectiveness of large fresh-water snails, *Marisa cornuarietis*, as a biological aquatic weed control agent. The snails controlled *Cerathophyllum demersum*, *Najas guadalupensis*, and *Potamogeton illineonsis* completely and *Pistia stratiotes* and *Alternanthera philoxeroides* partially. *Marisa* preferred submerged to floating weeds. Little damage was done by *Marisa* to 4- and 5-week-old rice plants, but younger rice was killed when the snails had no other source of food[47]. Except for its possible deleterious effects in rice-growing areas, *Marisa* was regarded as very promising for the control of aquatic weeds especially in confined bodies of water[48].

Alligatorweed, *Alternanthera philoxeroides*, is an extremely prolific plant which is most difficult to control and even more difficult to kill. It does not pose a serious weed problem in South America, where 40 to 50 species of insects act as suppressing biotic agents. Only one of these insects was known to occur in the United States and this insect, a flea beetle, belongs to genus *Agasicles*. During the fall of 1965 and spring of 1966, over 9,000 beetles were transferred to selected and approved locations throughout Florida, Georgia, South Carolina, and Mississippi. Frequent observations were made in the vicinity of the release sites and at no time was there any evidence

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that the beetle fed on any plant other than alligatorweed. The beetles prefer alligatorweed growing in the water. The results were promising[49] and have been extended. The possible use of herbivorous fish has received minimum attention in the United States. Common carp, *Cyprinus carpie*, may control some aquatic plants by keeping the water muddy, and, to a lesser degree by rooting out plants. In China, Japan, Israel, and Thailand the grass carp, *Ctenopharyngodon idellus*, has been used successfully for the control of rooted aquatics[37].

Since 1957, eight species of fish have been field-tested for effectiveness in aquatic weed control in Alabama. The Congo tilapia, *Tilapia melanopleura*, grass carp, and the Israeli carp, *Cyprinus carpio* have shown the best potential for weed control. In ponds, Congo tilapia, when stocked at rates of approximately 1,000 to 1,500 per acre, in three months controlled *Pithophora* sp., giant *Spirogyra*, *E. acicularis*, *E. densa*, *Hydrochloa* sp., *U. biflora*, and *Rhizoclonium* sp. Grass carp controlled *Chara* sp., *P. oviersifolius* and *E. acicularis* in one month when stocked at a rate of 20 to 40 per acre. 6- to 9-in. Israeli carp, when stocked at rates of 25 to 50 per acre, were effective in reducing or eliminating *Pithophora* sp., *Rhizoclonium* sp., *E. acicularis* but in some ponds required 2 to 3 years to effect control[50].

The species of fish receiving most of the attention in Georgia are: *Tilapia nilotica*, *T. mossambica*, *T. melanopleura*, *C. carpio*, and *C. idellus*. All observations on Chinese or grass carp, *C. idellus* were favorable[51]. In the spring of 1967, 2,000 grass carp were stocked in a 20-acre pond in Georgia that had a 5-year history of excessive growth of *Najas* and *Potamogeton*. Within 6 weeks, the grass carp was able to consume most of the rooted aquatic vegetation.

Parasites and predators are continually being colonized and evaluated for their effectiveness as control measures for various types of aphids, scales, moths and beetles[52].

STERILITY

The use of insect sterilization to control and eradicate pest populations is one of the revolutionary departures of modern entomology[53–56]. There are two ways by which the sterility principle might be used to control or eradicate insects. One method involves rearing, sterilization and release into the natural population so that the sterile members will compete with normal ones and thus lower the reproduction rate. Early experiments in sterilizing insects employed X-rays, but subsequently γ-rays from a cobalt-60 source were used. As an example, it is assumed that the natural population exists in an isolated area containing a stable population of two million insects with a 1:1 ratio of males to females in equilibrium with the environment and with the biotic potential canceled out by environmental resistance. For each generation, two million sterile males would be released to compete equally for mates. By the fourth generation, the ratio of sterile to fertile males competing for each virgin female would be 1,807:1; with equal competition 99.5% of these matings would be sterile[53].

Another method is to treat and sterilize insects in the natural population to

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reduce reproduction. The chemical compounds which reduce or entirely eliminate the reproductive capacity are called chemosterilants. Chemosterilants may affect only one sex (male sterilants, female sterilants) or both sexes (male-female sterilants). United States Department of Agriculture entomologists and chemists had screened 3,000 materials up to 1962 and found that at least 50 of them produce sterility in insects. Apholate and aphoxide are among the most active chemosterilants currently under investigation[54]. When administered orally or by contact these compounds produce irreversible sterility without apparent adverse effects on the mating behavior and length of life of the insects. Insects, which are ready for field testing, include fruit flies, mosquitoes, boll weevil, *Heliothis* complex, sugar cane borer, rice stem borer, pink boll weevil and cabbage looper[56].

Screw worms were brought to the vanishing point by the release of 100 sterile males per square mile per week on Sanibel Island near Fort Myers, Fla., but eradication could not be proved because the test area was not sufficiently isolated to prevent immigration of a few fertilized females from nearby untreated areas. Another experiment was performed on the island of Curaçao[55] where eradication was achieved on that isolated 170 square mile island. The apparent eradication of the screw worms from Curaçao supported the theory that screw worms could be eradicated from the Southeastern States by releasing sterilized flies. In July 1958, a large sterilized fly production facility was completed at Sebring, Fla. This establishment produced fifty-million sterilized flies per week, which were distributed over all infested areas in the Southeast (Florida, Georgia, Alabama, Mississippi, South Carolina, North Carolina). By 1958, the screw worm had been essentially eliminated from the Southeastern States, the major area of the continental United States in which this pest can overwinter, and no significant infestations of screw worms have since occurred[57]. The screw worms were irradiated with γ-rays using a cobalt-60 source[58]. This was one of the most successful controls of an economically important pest.

Eradication of the cotton bollworm from St. Croix, U.S. Virgin Islands, was attempted in 1968 and 1969, using the sterile-male release method[59]. Both attempts failed in the primary objective of eradicating the species. The reasons were the high ratios of sterile to natural males which caused the elimination of oviposition, and the high degree of locking between the released population and the native females.

A truly effective chemosterilant for the boll weevil has yet to be discovered. Some of the aziridinyl compounds, particularly apholate, induce a rather high degree of sterility in the males, but the mortality of treated insects is high and their competitiveness is reduced[60]. During 1962, apholate-sterilized male boll weevils, *Anthonomus grandis*, normal males and virgin untreated females were released in three experimental 1-acre plots of cotton in Virginia, Tennessee, and Lousiana in the ratio of 20:1:1 in each of five uniformly distributed points. A total of 8,850 sterile males released over an eight-week period prevented matings between the ensuing F_1 males and females. On the seventeenth week of the experiment, no egg or feeding punctures were found in two examinations of all the squares and bolls on plants in the field. Only in the Louisiana experiment was eradication of the population achieved[61]. The successful eradication in 1962 of an artificially induced infestation of boll weevils

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prompted further studies. From June 17 through August 26, 1964, eleven weekly releases of apholate-sterilized male boll weevils were made in nine cotton fields that had been treated with insecticides in the fall of 1963, to reduce the population of diapausing weevils. An average of 8,200 males were released per acre in Baldwin County, east of Mobile, Ala. This release program reduced the number of oviposition punctured squares. Also, the percentage of infertile eggs, the number of live immature and adult weevils per acre in fruit, numbers of overwintered adults and the levels of infestation during the second year were considerably lower in the release zone than in the zone treated intensively with insecticides.

Effectiveness of apholate in decreasing the sperm viability of the male boll weevil was determined[62] in Misisissppi by allowing the weevils to feed on a diet containing 0.001 to 0.020% of the chemosterilant and on plants sprayed with 0.5 and 2.5% solutions. After both treatments, virgin females mated to treated males oviposited eggs with decreased hatchability and emergence of the F_1 progeny. At the higher levels of treatment, longevity of males was reduced. Repeated spray applications of the chemosterilant to plants, especially at the higher levels, caused phytotoxicity manifested by leaf necrosis, stunting of growth and cessation of square production. The male boll weevil can also be sterilized with tris-(1-aziridinyl)phosphine oxide (TEPA), either by feeding 1,500 ppm of TEPA in the diet for two days or by an injection of 3.5 mg (ref. 63). Lower levels of TEPA produced transitory sterilization. At the effective levels mortality was significant.

Three compounds, aphoxide, aphomide, and apholate, caused sterility in male and female house flies at concentrations of 0.5 to 1% in food given to the adults[64]. Of 97% compounds administered in granulated sugar or in fly food tested in Florida, only 27% caused sterility in adult house flies, *Musca domestica*[65].

Corn meal baits containing 0.5% of aphoxide (1-aziridinyl phosphine oxide) a chemosterilant, were applied on an isolated refuse dump in the Florida Keys for the control of house flies. Applications were made each day during the second week. House-fly populations were reduced from 47 to 0 per grid within 4 weeks and the percentage hatch among all eggs laid was reduced to 1% within 5 weeks[66]. House-fly baits containing 0.5% of metepa, methaphoxide, tris-(2-methyl-1-aziridinyl)phosphine oxide, were applied to the droppings in a poultry house in the suburbs of Orlando, Fla., for house-fly control. Applications were first made at weekly intervals for 9 weeks, then semi-weekly. Granular baits with corn meal as a carrier were the most effective[67,68].

The cotton bollworm, the armyworm, *Pseudaletia unipuncta* and the granulate cutworm, *Feltia subterranea*, can be sterilized with TEPA. Males of each species are sterilized when they are fed 53 mg of TEPA in a 10% sucrose solution. A dose in excess of 106 mg is required to sterilize female cotton bollworms and a dose of more than 53 mg to sterilize female armyworms and granulate cutworms[69]. Sterilization of the fall armyworm by apholate and TEPA has also been reported[70].

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ATTRACTANTS AND REPELLENTS

Many insects find their food, their mating partners and favorable sites on which to deposit their eggs by an automatic response to various scent clues. Male moths, for example, can detect potential sexual partners at great distance. Not surprisingly, each species tends to have its own distinctive odor which facilitates the meeting of mating partners. Frequently insects can be attracted by means of a chemical. This is useful for pest detection purposes or to expose them to an insect pathogen, toxicant or a chemosterilant[71].

Attractants have been classified into three categories; sex, food, and oviposition lures. The type of lure is inferred or deduced from insect behavior and the designation given to such response is frequently uncertain. If exposure to a chemical causes a male insect to assume a mating posture, the chemical is probably a sex attractant, even if it is a synthetic and unrelated to any natural lure. Some entomologists believe that methyl eugenol, the attractant for the oriental fruit fly, *Dacus dorsalis*, is a sex attractant because the chemical attracts only the male. However, it also appears to be a food lure, because the flies avidly devour the chemical[72]. A similar example is the attraction of the cucumber beetle, *Diabrotica undecimpunctata howardi*, to cucurbitacin, a terpenoid compound present in its host plants[73]. Food-based or fermenting lures have a definite place in control operations. Disadvantages include lack of specificity (traps fill with many kinds of insects), attraction over only a short distance, rapid deterioration (especially of fermenting lures), and frequently inconsistent performance. In regard to oviposition lures, females have been induced to lay their eggs on, or in the vicinity of, certain chemicals. Materials that release ammonia are known to encourage oviposition in house flies. The apple maggot is attracted to decomposing proteins, such as egg albumin[72].

Chemical attractants and associated agents, such as stimulants and assertants, have been widely used for many years in studies of insect behavior. They have served many useful purposes as lures in traps, *e.g.* to sample insect populations; to determine relative densities from time to time and from place to place; to trace the movement of marked insects in dispersion and migration studies; to study survival of insects in their natural environments; and to study behavior associated with the search for mates and oviposition sites.

In the search for selective methods of insect control, many entomologists and plant protection personnel are seeking chemicals which elicit repellence. A repellent is a chemical that causes an insect to make oriented movements away from its source[8]. The distance the insect needs to move, however, is usually much shorter than the distance it does move in response to an attractant. Ordinarily, it only needs to leave or avoid a treated surface or at most move a few centimeters out of the effective concentration of repellent vapor. Less use has been made of repellents for the protection of animals and plants than for the protection of man.

Ultimately attractants must be tested in the field where they must prove effective despite a multitude of natural odors, colors, light conditions, and weather[72,74-76]. Examples of some potent synthetic attractants are cuelure, siglure,

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medlure and trimedlure for various types of fruit flies; gyplure for gypsy moth; and grandlure for cotton boll weevil[72].

In 1956, the Mediterranean fruit fly reappeared in Florida after an absence of 26 years. Following its initial eradication in 1929–1930, the on-tree annual value of the citrus crop had climbed to about 250 million dollars and that of all other commercial hosts of this pest was many million dollars more. It was estimated that if these flies were not eradicated the combined annual cost of control efforts, fumigation of exported fruit, and maintenance of quarantine and road blocks would approximate 20 million dollars exclusive of crop losses and decrease of consumer acceptance of the state's citrus products. The statewide eradication involved aerial spraying of protein hydrolysate and malathion. Quick action by state and federal agencies (Plant Pest Control and Entomology Research Branch, U.S. Department of Agriculture) and industry, along with good public support, made it possible to complete effective curtailment and eradication programs in a minimum of time[77].

Two terpene alcohols and two terpene aldehydes from male boll weevils were isolated and identified at the Mississippi State University in 1969 (ref. 78). These compounds are the components of the pheromone to which only female boll weevils respond in laboratory tests. In bioassays, mixtures containing all four compounds elicited a response by females equivalent to or better than that elicited by live males[79]. Absence of either alcohols or the two aldehydes from the mixture resulted in almost complete lack of response. The response to the mixture of synthetic compounds was identified to that obtained from corresponding mixtures of natural compounds. The extract of fecal material of boll weevils (both male and mixed sexes) produced a material highly attractive to females but not to males. The synthesized pheromone was named grandlure. This compound, however, had a very short life. Polyethylene glycol increased its life. This stable product became an agent in surveying boll weevil infestation[80].

The pine sawfly, *Diprion similis*, is a pest of eastern white pine. It was observed that large numbers of males swarmed toward females. Investigations were conducted to determine whether a sex attractant was involved. A virgin female was placed in the screened portion of a trap and tanglefoot was spread over another portion. The traps were suspended from trees in the infested areas. An average of 1,000 males were attracted in each of eight traps. A large number of males also fell to the ground. Some females did not attract males for an unknown reason. The male response was rapid. Many approached within 30 sec after the traps were placed. Traps positioned at an angle of 90° to the wind direction at the edge of the wood were consistently more attractive than those set in dense woods. Greatest activity took place from mid-morning to sunset. One trap with a virgin female exposed from 11 a.m. to 4 p.m. attracted more than 7,000 males. She continued attracting males at approximately 1,000 per day until she died on the fifth day, after which small numbers were still caught over the next three days. Males were lured 200 ft. from the forest over an open field. Chemosterilant-attractant mixtures can be effective in reducing or eradicating a field population of this insect[74].

Epidemics of the southern pine beetle, *Dendroctonus frontalis*, have occurred

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periodically throughout the southeast and in parts of Texas. A remedial method presently being tested employs frontalure (1,5-dimethyl-6,8-dioxabicyclo[3.2.1] octane), the sex pheromone, to aggregate southern pine beetle population on the trees to be harvested and/or treated with cacodylic acid, which checked brood development but does not harm non-target insect. In fact, the simultaneous aggregation and survival of predators and competitors has become an integral part of this control method. Aerial surveys monitor southern pine beetle activity. Infestations can be treated immediately by the crews performing the ground check. Few tools are needed and the amount of chemicals deployed does not surpass gram quantities per acre[81].

HORMONES

An approach to pest control is based upon the rapidly expanding knowledge of how insects rely upon hormones to regulate their growth, feeding, mating, reproduction and diapause or overwintering[76]. The primary candidate for control measures is the juvenile hormone that all insects secrete at certain life stages[82]. The potential utilization of this information for insect control depends upon the ingenuity with which man can supply a juvenile hormone to the insect at an unfavorable stage. The contact of a last-stage nymph, larva or pupa with a juvenile hormone induces morphogenetic damage. This results in the development of intermediates or monsters which are unable to mature and die in a short time. Investigations have revealed other important functions of the juvenile hormone in insects including diapause, reproduction, embryogenesis, sex-attractant production, and lipid metabolism[76].

The synthetic juvenile hormone analogue, *trans,trans*-10,11-epoxyfarnescenic acid methyl ester, successfully terminated adult diapause in several species of *Hemiptera*, including the box elder bug and the red linden bug[83]. Juvenile hormones are unquestionably deeply involved in the regulation of diapause and the possibility exists that further research may result in the development of antihormones which can prevent or even induce diapause.

A male *Pyrrhocoris* treated topically with 1 mg of dichloride compound, synthetic juvenile hormone, is able to transfer enough of this chemical to females by contact during mating to induce sterility. This novel method of transmitting sterility should have interesting field applications if similar chemicals affecting insects other than *Phyrrhocoris* are developed. Williams[82] believes that synthetic juvenile hormone eventually will prove to be most effective as an egg killer (ovicide). Ecdysone is another insect hormone which has the potential of becoming a selective insecticide. This substance initiates ecdysis (shedding of skin) or metamorphosis from one stage to another in the larval or nymphal development of insects. Overstimulation with ecdysone results in repeated metamorphosis without sufficient time for the accumulation of food reserves so that eventually the larva or nymph becomes exhausted and dies.

From the foregoing it is obvious that the application of morphogenetic compounds to immature insects can kill them by upsetting their development. The

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practical utilization of these compounds becomes attractive with the realization that these hormonal effects are specific to insects. In addition, these chemicals have no effect on other forms of life[76,82]. A further advantage is that insects cannot develop immunity against the compounds for if they did, they would become immune to the hormone that is essential to part of their life cycle. Since this discipline of pest control is still little explored, specific case studies are not available.

GENETIC MANIPULATIONS

The first attempt at control by the application of genetics involved the tsetse flies, *Glossina* sp. Interspecific crosses were made of *Glossina swynnertoni* and the reproductively but not sexually isolated *G. morsitans*. Viable but sterile offspring were obtained from such crosses, which competed with normal individuals for survival in the environment[56]. Many lethal genes exist in populations of insect species that have been subject to genetic analyses. Deleterious genes need not be lethal nor act immediately for effective control. Drastic reductions in insect numbers can be obtained theoretically by constant low-level mortality factors superimposed on populations already exposed to the stress of adverse environmental conditions as, for example, low temperature during hibernation. Three requirements are essential to the success of control measures utilizing the release of strains carrying unfavorable genetic characters: the factors must not prevent rearing under laboratory conditions; they must not interfere with mating ability; and they should act at particular times, such as during the hibernation or immature stages. It has been postulated on theoretical grounds that the eradication of the boll weevil could be achieved in a few years if males carrying two lethal genes were repeatedly released into field populations. It should be considered that such additional release of pests could temporarily increase the loss of the crop until lethal genes are inherited and come into effect. Although genetic methods seem to offer promising leads, considerable research is needed before such techniques can be incorporated at a practical level.

PREVENTION OF SPREAD

One of the methods by which weeds spread is through their inclusion with crop seeds. As early as 1821, Connecticut passed a law prohibiting the sale of grass seed containing Canada thistle and other weeds. The earliest vegetable seed laws were adopted by Florida in 1889. By 1941 all 48 states had seed laws. The federal seed act[84] requires, in part, that the following information be provided on seed labels in interstate commerce: percentage of pure seed of the named crop, percentage of other crop seeds, percentage of weed seeds, and the rate of their occurrence. Crop seeds cannot be sold for seeding purposes in most states if they contain noxious weeds in excess of a specified percent by weight of weed seeds, generally 2 or 3%. The model state seed law, used as a guideline for legislation by many states, provides a typical example of state regulations. Noxious-weed seeds are separated into two classes: prohibited (generally annuals) and restricted (seeds of perennial weeds). Seed

laws at state and federal levels have been important in reducing the spread of weed species and in improving seed quality[84]. Seed certification is the system used to keep pedigree records for crop varieties and to make available sources of genetically pure, disease-free seeds and propagating material for general distribution. Without such a system, seeds tend to become contaminated and mixed and lose identity. Certified seeds contain relatively fewer weed seeds[85].

There are at present no practical and economical treatments to cure virus-infected plants in the fields. Methods of control, therefore, are generally directed toward preventing infection by eliminating the source of inoculum, by preventing spread of virus, or by developing varieties immune to the virus or immune to the disease they cause. The production and distribution of "virus-free" propagating material has proved highly successful in controlling virus disease in many crops. The term virus-free can be defined as free from the known and specified viruses for which tests have been conducted. The tactics of virus control depend upon integration of several distinct activities: the recognition and characterization of the virus diseases in each crop; the development of reliable indexing methods to retrieve any existing healthy stock, to sort plants that have been treated to eliminate virus, and to detect any symptomless carriers; the development of techniques to rid a few selected plants of virus and establish clones of virus-free foundation stocks where no healthy material is found; and, the enactment of measures such as certification programs to maintain the health of foundation stocks, and to secure effective distribution of their progeny to growers and nurserymen. In the United States, certification programs are individual state functions. A certification program for virus-free citrus stocks is presently used in Florida. Such programs tend to keep a control on the known viruses of crops propagated from vegetative stocks[18].

In agriculture, quarantine refers to the restraints or restrictions placed upon the transportation of animals, livestock, poultry, plants, fruits and vegetables, plant and animal products or other materials which are suspected of being carriers of agricultural pests. Such precautions are necessary, as many of the worst plant pests came from other countries and thrive here because of abundant food and few natural enemies. The tempo of international travel has greatly increased and with it the danger of spreading pests has also increased. The quarantine system is a necessary element of overall national preventive pest control programs[86]. Domestic quarantines between states, combined with treatment programs, have eliminated several pests from the United States. For example, Japanese beetle, *Popillia japonica*, has been under continuous regulation in the United States since 1919. Established infestation still does not exist west of the Mississippi River, and occurs only in isolated areas in the southeast. Control and quarantine programs have confined the gypsy moth, *Porthetria dispar*, to a few northeastern states although there are some 100 million acres west of the Mississippi River known to be susceptible to attack[8].

Publicly supported regulatory programs are an essential part of the overall effort to protect crops and livestock from pests. Various methods are used in eradication, containment and suppression programs; these include chemical, cultural and biological measures. Greater merit is indicated for large-scale alternative control

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programs as compared to region-wide chemical spraying. Many of the alternative techniques of pest control are employed over larger areas than individual farms. Programs of state and federal agencies in cooperation with private agencies and individual farmers will be required in pest control.

The detection of pests and surveys of their distribution and abundance are essential prerequisites to rational control programs. The first principle of pest detection and surveys, as related to control, is that no measures should be undertaken against a pest unless it is known to actually be present above economic injury level. Often this basic premise is not followed.

In 1971, cotton insect scouting programs were conducted in ten southeastern states. Scouts surveyed 877,225 acres out of 10,421,000 acres under cultivation. Such programs have been in operation for 9 years in Alabama alone. Scouted cotton fields have averaged 200 more pounds per acre in lint than fields not scouted. A scout who has received special training by an extension service entomologist can keep growers informed of the following: when the infestation count is great enough to warrant starting a control program; when to expect hatch out of boll weevils or bollworms; and, how long to continue the control program into the fall. Scouts give farmers weekly written insect reports and also send infestation reports to county extension chairmen and to extension entomologists. Each week, reports are summarized and a copy sent to all county extension chairmen and other agriculturists in the state[87]. Although no information is available regarding the actual reduction of pesticide used, it is postulated that many applications are eliminated without economic loss. Surveillance can only be effective over large areas. Sufficient understanding of pest ecology and biology exists so that such programs can be promptly initiated. Extension services and agricultural universities can play an important role in such activities.

SAFER PESTICIDES

It is widely accepted that although alternative technology exists, conventional chemicals will remain the chief means of insect pest control for the foreseeable future[5,88,89]. The rationale for this lag in the use of alternative methods merits explanation. There has been a growing concern over certain known and potential threats to the quality of our environment because of the use of the broad-spectrum pesticides. This concern, however, has not been fully translated into increased commitment of resources toward search, development or large-scale testing of safer pesticides and alternative methods. Most of the widely used chemicals for control have been selected on the basis of optimum effectiveness against the pest and for maximum persistence.

The original DDT patent of 1939 covered a number of insecticidal analogs[88]. These included methoxychlor, ethoxychlor and methylchlor. All of these compounds are persistent insecticides effective against a wide spectrum of insect pests and they are relatively inexpensive. DDT is the most stable and has had the most extensive use, whereas methoxychlor has been used on only a modest scale, and ethoxychlor

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and methylchlor not at all. These DDT-related compounds are rapidly degraded by the multifunctional oxidases of higher animals and converted to water-soluble compounds. DDT is not. Similarly, the related compounds are less toxic to fish. Ethoxychlor, methylchlor and other biodegradable derivatives of DDT merit further investigation as replacements for DDT and other persistent and non-biodegradable chlorinated hydrocarbons. Safer analogs (fenthion, ronnel, dicapthon) exist for methyl parathion, the most commonly used organophosphate. Consideration should also be directed toward the effect of these pesticides on the natural enemies of pests and beneficial insects[90].

INTEGRATED CONTROL

Integrated control combines several agronomic practices and pest control methods. The total effect of these combined methods is synergistic rather than additive. Integrated control is predicated on a fundamental ecological basis[91]. The concept includes appropriate combinations of pesticides, natural enemies, insect pathogens, cultural treatments, etc.[30]. It emphasizes the ecosystem and stresses economic levels[92].

A large-scale experiment is currently underway to eradicate the cotton boll weevil. The test area is 150 miles in diameter and is located around Gulfport, Miss. This two-year study will end on July 1, 1973. At that time researchers will have determined if eradication is feasible, and what the cost will be. Presently it is estimated that the total cost of eradication might be about $275,000,000. For the first time, treatment involves at least six simultaneous operations. These include in-season spray, as needed; a series of reproduction–diapause sprays in the fall to prevent over-wintering; defoliation; stalk shredding; and pheromone traps for males to prevent reproduction by surviving males. In addition, continued experiments with frego bract weevil resistant cotton, and temik systemic insecticide will be part of the program. The chief weapon will be diapause control by a series of up to seven fall sprays applied mainly by five helicopters in core zone, Columbia, Mississippi, and the first buffer zone, spilling over slightly into Alabama and Louisiana. Properly timed, this treatment can kill up to 99% of weevils entering hibernation. Chemicals used will be ultra-low-volume guthion or malathion, depending upon the environmental hazard involved. In the spring, adhesive-coated traps baited with grandlure will be placed on fence lines. These traps should catch about 80% of the emerging weevils. A single application of insecticide before square drop should kill about half of the surviving weevils, without permanently suppressing beneficial insect populations. The sterile males will then be released at a density of 50 to 200 per acre for several generations, and theoretically should reduce the native population by 98% with each generation[5,93]. If the eradication of the boll weevil should eventually be possible at a cost comparable to the annual losses for just 1 year, such a program would be one of the best investments the cotton industry could make. Perhaps even more important, the elimination of this insect would be the greatest single contribution that could be made in the foreseeable future toward the goal of reducing environmental pollution caused by the use of broad spectrum insecticides.

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Recent unpublished theoretical studies suggest that the mass production and programmed releases of one or more species of selective *Heliothis* larval parasites may also provide an effective and highly selective means of managing *Heliothis* populations. Relatively little is known about the numerical relationship between parasites and their hosts. However, based on a theoretical appraisal, there is good reason to believe that it is well within the realm of feasibility to mass produce and release sufficient selective parasites to truly manage insect populations like the *Heliothis* species. This system of insect population management should have its maximum efficiency when the host insect populations is high and should have diminished efficiency when it is low. This is just the reverse of the potential efficiency of the genetic approach. Therefore, the parasite release technique and the genetic technique may eventually prove to be highly complementary when they are integrated into one system of suppression. Environmental factors that induce and terminate diapause in *Heliothis* should also be elucidated to aid non-chemical control[94]. Insect pathologists are making considerable progress in developing microbial agents which may further strengthen an integrated approach.

Control of hornworms, *Protoparce sexta* and *P. quinquemaculata*, on tobacco with insecticides is not completely satisfactory in North Carolina. When *Polistes* wasps were induced to nest in shelters erected around the field, populations of fifth-instar hornworms were reduced by about 60% and damage by 76%. One-fifth of the recommended rate of insecticides TDE or endrin, applied as top sprays gave reliable and adequate control of both hornworms and budworms. This was true whether insecticide was applied every two weeks on a preventive schedule or only when counts indicated treatment was needed[95]. An integrated program would be more economical than present systems and would reduce residues to a fraction of the present levels.

The introduction of the beetle, *Agasicles* sp. as a biological control agent has been an added deterrent to the growth of alligatorweed, *Althernanthera philoxeroides*, through the Atlantic coast states. However, floating mats have been controlled in only very small local areas where herbicides have not been used. The recommended chemical control of alligatorweed is two or more treatments of silvex. Alligatorweed may be controlled with less herbicide in the presence of large populations of alligatorweed flea beetles. A dense mat of alligatorweed was treated with silvex and a beetle population of one adult per 2sq. ft. of mat was introduced when regrowth was 2 to 5 in. high. The beetles showed a feeding preference for the young regrowth over the more mature non-treated alligatorweed and maintained sufficient feeding pressure to eliminate the floating mat growth[96].

Integrated control today has acquired greater acceptance than when it was proposed 15 years ago. Broadly, it refers to integration of all crop protection procedures. Integrated control programs in general required a higher level of scientific background when compared to chemical control. At least a minimum level of information is usually needed regarding the following points: the general biology, distribution and behavior of the key pests; an approximation of the pest population levels that can be tolerated without significant crop loss; a rough evaluation of the times and places of occurrence; and the significance of the major predators, parasites,

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and pathogens present; and information on the impact of the use of pesticides, insecticides, herbicides, and fungicides, as well as other control measures on natural enemies, and on natural and agroecosystems.

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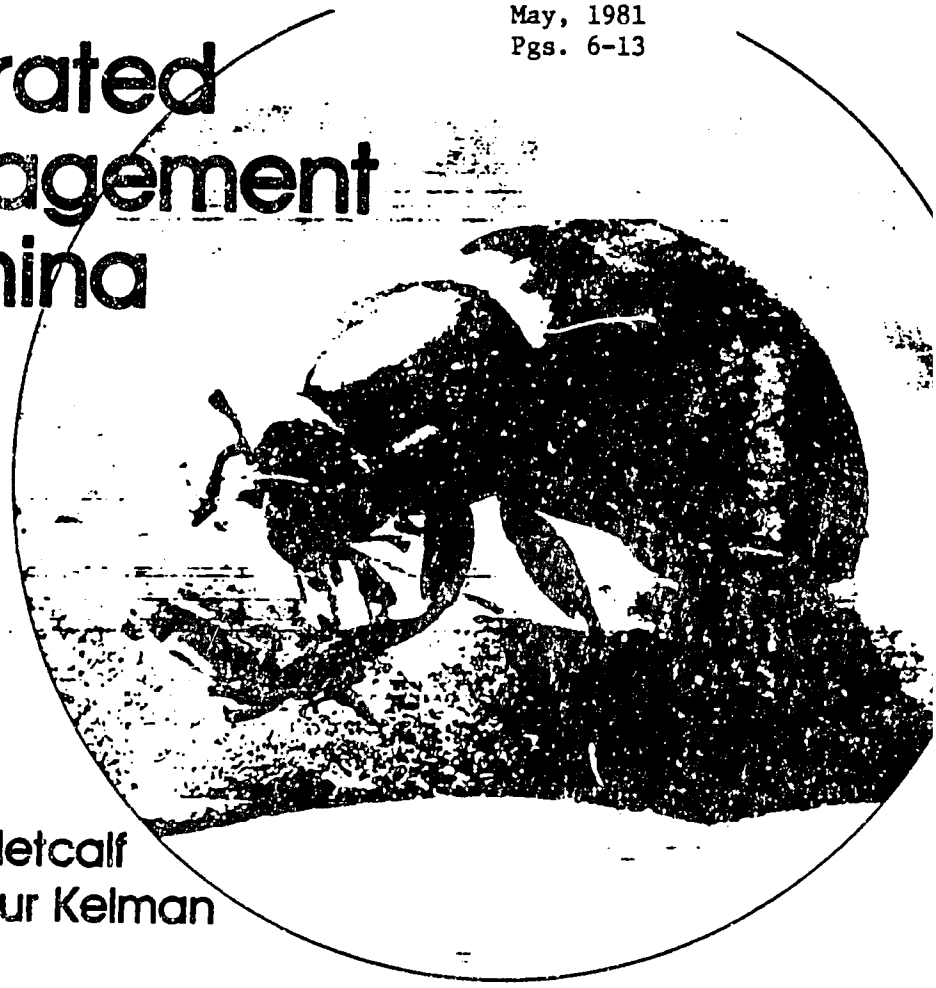
Integrated Pest Management in China



by Robert L. Metcalf
and Arthur Kelman

China's 5,000 years of continuous, recorded civilization provide an unequaled perspective on pests and pest control. During this time, the Chinese have experienced almost every pest problem incident to agriculture and have practiced an astonishing array of pest control methods. The Western world has remained largely unaware of some of these approaches because of cultural and linguistic barriers, as well as our missionary emphasis on teaching in lieu of learning.

Today the West recognizes that satisfactory pest control is not a simple matter of routine application of pesticides, but rather a far more complex ecological effort. This makes it important to understand the experience of China, where some of the principles of integrated pest management (IPM) were enumerated over a thousand years ago.

The earliest organized efforts in Chinese insect control came with the depredations of the migratory locust, *Locusta migratoria manilensis*. Recorded locust plagues date back to 707 B. C.[1] Since then, more than 800 outbreaks have occurred in various parts of China, chiefly in the flood plains of the Yellow, Huai, and Chang Jiang (Yangtze) rivers and in the coastal regions to the south.[2] Successive outbreaks of locusts in a given locality have occurred every 3 to 15 years and lasted from 12 to 30 months.

The severity of the problem can be judged by the 1929 outbreak, which devastated more than 11 million acres of cropland, causing illness, starvation, death, and wholesale migration from the affected area.[3] Another disastrous locust outbreak occurred in 1938 when Nationalist soldiers destroyed the dikes along the Yellow River and locusts breeding in the flood plain caused damage in about 140 counties in ten provinces.

The earliest record of locust control dates back 3,000 years to a Shang dynasty (1523-1027 B.C.) poem, which describes the use of flames to destroy locusts. About 2,000 years ago in the Han dynasty (202 B.C.-A.D. 220), Wang Zhong (Wang Chung) described the use of open ditches to trap immature locusts. In A.D. 2, government officials offered bounties to peasants for collecting locusts. During the Tang dynasty (618-906), burning and trapping were successfully combined. During the Song dynasty (960-1279), the digging of locust eggs from the soil was described, and in

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1182 a law required citizens to collect and destroy locusts. This is very likely the first example in the world of a legal requirement for pest control.

By the Ming dynasty (1360-1644), the locust's behavioral traits, such as migrating upwind and early in the morning during heavy dew, its reluctance to fly at dusk or in the afternoon after mating, and its tendency to fly low after rain and toward flames, were described in simple texts and diagrams. Around 1600 Shen Guangjing called for preparations for locust invasions at a national level. Other innovations of this period included the planting of legumes, which locusts do not eat, and the herding of ducklings in fields to act as biological control agents.[4]

In ancient times, Chinese peasants were virtually helpless in combating the recurring locust plagues. Confucius (551-479 B.C.) regarded locust outbreaks as natural calamities and part of heaven's will. Despite advances in knowledge in the subsequent two millennia, effective locust controls only became available after the Revolution in 1949 when China began to mobilize rural manpower on a vast scale to combat the locust menace.

During the early 1950s manual destruction was practiced extensively. Locust eggs were dug up in winter and destroyed; trenches 20-30 kilometers (km) long were dug and young locusts driven into them and buried. Thousands of peasants encircled infested areas and killed locusts with bamboo brooms and locust swatters made from shoe soles nailed to wooden poles.[5]

Dusting with benzene hexachloride (BHC) began in 1951, and the use of aircraft for dispersal increased from 13.7 percent of locust-infested areas in 1958 to about 54 percent in 1960 and about 70 percent in 1963.[6] By this time the Chinese realized that they had relied too heavily on aircraft application of insecticide, which was not only costly but also had deleterious effects on beneficial insects and environmental quality. Moreover, the use of insecticides had weakened locust control organizations and delayed the accumulation of sound ecological information about locust control.

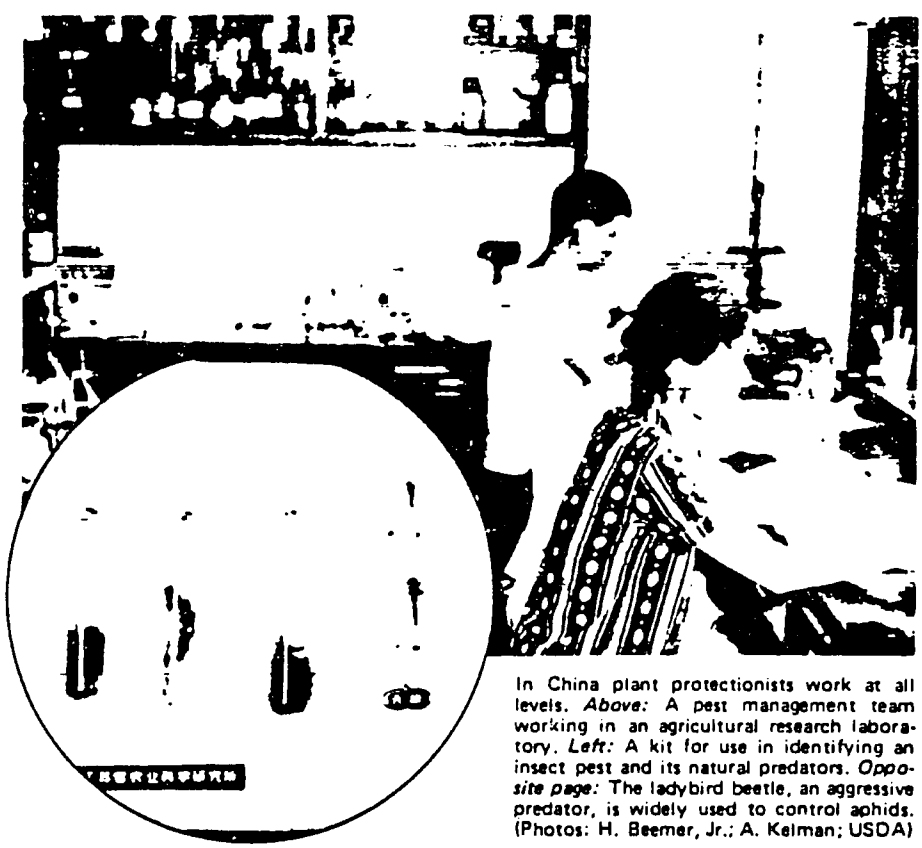
As a result, the use of aerial spraying was curtailed and by 1975 was virtually abandoned.[7] Yang Xiandong, vice-minister of agriculture, said in 1963 that the density of locusts had been reduced but the area of infestation had not decreased.[8]

More than 120 million persons participated in pest management programs for migratory locusts following a major outbreak in 1951. Primitive methods of surrounding, whipping, and burning locusts were supplanted gradually by more ecologically oriented efforts directed by stations surveying locust-breeding grounds and forecasting outbreaks on the basis of meteorological conditions. From 1958 on, enormous efforts were made to convert breeding areas in reedy, riverside flood plains into rice paddies, forest belts, and pastures. More than one million hectares (ha) of mountainous farmland in the Yellow River valley were converted into terraced fields. Four million check dams and 27,000 small reservoirs were constructed on small tributaries to control flood surges, and trees and grasses were sown on 4 million ha.[9] This campaign represents the most extensive pest management program of all time.

Today, rather than relying primarily on insecticides for locust control, China has developed an imaginative and practical approach for the environmental control of locusts that knits together biology, meteorology, water management, and cultural practices and relies heavily on forecasting.[10]

Importance of Plant Protection

China is still an agrarian society. Four-fifths of its population reside in rural areas where they engage primarily in producing food and fiber for themselves and urban dwellers.[11] Thus, agriculture is China's most important activity, and its farms currently produce enough food to feed about one billion people, or more than one-fifth of mankind. Scientists and agriculturists who have visited China since 1972 have commented, almost without exception, that the Chinese people appear exceptionally healthy and well nourished.



In China plant protectionists work at all levels. *Above:* A pest management team working in an agricultural research laboratory. *Left:* A kit for use in identifying an insect pest and its natural predators. *Opposite page:* The ladybird beetle, an aggressive predator, is widely used to control aphids. (Photos: H. Beemer, Jr.; A. Kelman; USDA)

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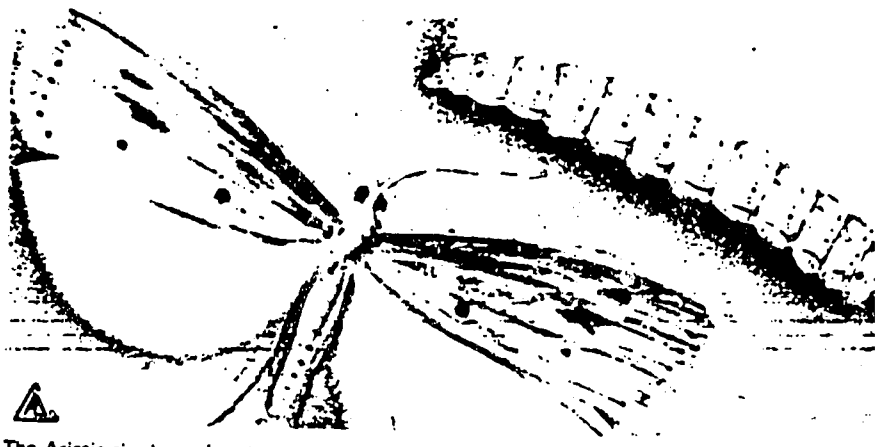
China has only about 107 million ha of arable land (compared with 156 million ha in the 48 contiguous United States), yet China is essentially self-sufficient in food production.[12] The success of plant protection and improved agronomic practices can be gauged by the increase in grain production from about 113 million tons in 1949 to 175 tons in 1974.[13] In comparison, the United States produced about 194 million tons in 1973. In 1976 China imported about 4 million tons of wheat, but this was partially offset by the export of about one million tons of rice.[14] These figures, as well as the observations of visiting scientists, indicate a highly successful and expanding agriculture.

China has attained virtual self-sufficiency in agriculture largely because of the enforcement of Mao Zedong's dictum: "Take agriculture as the foundation." Thus, hundreds of millions of man-years of effort are concentrated in rural areas, and large monetary resources are channeled into food production.

The financial commitment of China's leaders to agriculture has been estimated at U.S. $5 billion annually.[15] Agricultural production has been bolstered by extensive double and triple cropping in Central and South China, vast terracing and irrigation schemes in the North China Plain, and the development of area fertilizer programs to ensure optimum crop fertility.[16] It appears that crop yields and production have now been pushed close to their natural limits.[17] Therefore, the great challenge for the future will be to cope with a natural population increase now estimated at slightly over 1.5 percent each year. This population growth will require about 4 million additional tons of grain annually and ensures that agriculture will remain an area of paramount concern.

Protecting plants from pest attack is an obvious way to increase the available food supply without creating new agricultural land, improving irrigation, or increasing fertilizer production. Indeed, China's success in maintaining self-sufficiency in food production will be a measure of its achievements in controlling plant diseases and insect pests.

Detailed recent data are not available on crop losses from pest attack in China. However, in 1937 it was estimated that insects and plant diseases caused a 10-20 percent reduction of Chinese grain crops.[18] Another, more recent report in 1962 by the Bureau of Plant Protection of the Ministry of Agriculture suggested that in seriously affected areas grain losses were about 10 percent, cotton 20 percent, and fruits 30 percent of total production.[19]



The Asiatic rice borer (moth and larva). Although the precise magnitude of pest damage to Chine agriculture is unknown, it is clear that losses are significant enough to warrant major government efforts to curb them. A 1967 estimate places the loss of rice production to insect pests at 15 pe cent. (Photo: USDA)

In 1967, in a thorough compilation of pest losses in agriculture, H. H. Cramer presented data for crop losses in the People's Republic of China based largely on comparable data from Southeast Asia and the U.S.S.R.[20] These data suggest that the percentage losses to insects and plant diseases respectively are: rice, 15 and 8 percent; corn, 12.4 and 9.4 percent; wheat, 5 and 9 percent; cotton, 16.1 and 12 percent; sugarcane, 20.1 and 19.2 percent; apples, 13.2 and 13.7 percent. The accuracy of these loss estimates may be subject to question because they were 10 to 20 years out of date and did not allow for the immense progress made in plant protection in China under communism. Moreover, the possibility that crop losses to pests in China are significantly higher than in the United States is not substantiated by the observations of American scientists who have visited China recently.[21]

Although the precise magnitude of pest damage to Chinese agriculture is unknown, it is clear that losses are significant enough to warrant major governmental efforts to curb them. In 1958 the Ministry of Agriculture's Bureau of Plant Protection planned for thorough control of plant diseases and insect pests on 12.03 million ha of cropland in 18 provinces and municipalities.[22] Included were 3.6 million ha of rice, 1.6 million ha of wheat, 4.1 million ha of miscellaneous grains, 2.4 million ha of cotton, and 0.22 million ha of fruits and other economic crops. It was estimated that this control program could save 1.25 million metric tons of grain and 90,000 metric tons of cotton.

Such strenuous efforts have had substantial effects, and in April 1960 Vice-Premier Tan Zhenlin reported to the Second National People's Congress that substantial blocks of farmland had been freed from such pests and diseases as aphids, red spider mites, locusts, army-worms, rice borers, and wheat smut.[23] In 1962 Vice-Minister of Agriculture Yang Xiandong said that pests on 27 million ha were controlled by pesticides and that more than 2.67 million tons of grain and had been harvested as a result.[24]

Plant protectionists work at all levels of government. At the commune and brigade levels, they diagnose plant health problems, forecast outbreaks of pests, apply control measures, and organize demonstration plots. Sometimes a plant protectionist, together with a veterinarian and a paramedic ("barefoot doctor"), is assigned to a production brigade.

More commonly, plant protectionists and agronomists function as a special research group in a commune. In Shaanxi province, for example, 50 percent of the communes are reported to have such teams, as well as simple laboratories designed specifically for crop protection work. These are equipped

with microscopes, manuals for the identification and control of plant diseases and insect pests, reference collections of common insects and diseased plant specimens, and beautifully detailed posters illustrating the life cycles of important pests. Facilities for culturing organisms used in biological control of insects are sometimes available.

The plant protectionists are usually enthusiastic, dedicated, and well acquainted with the applied aspects of their disciplines. They are almost unique in the cooperation and rapport they have with peasants, who regard the control of plant diseases and insect pests as one of their primary responsibilities to the state and their communes.

Pest Control Technology

The most successful aspects of plant protection research in China have been the large-scale development and implementation of programs for practical integrated pest management (IPM—see box). In China, as elsewhere throughout the world, the need to develop IPM programs for major agricultural pests is urgent. The strategy of single-factor pest control interventions using insecticides that seemed so promising in the post-World War II era has become increasingly less attractive because of the development of resistance to insecticides by hundreds of species of important insect pests, disturbances of agro-ecosystems that have resulted in the appearance of devastating secondary pests, widespread environmental pollution by persistent and toxic chemicals, and rapidly increasing costs of pesticides.

IPM has a higher social priority in China than in any other part of the world, and it has brought steady and sometimes spectacular success to agricultural production and crop protection.[25] The following sections review China's major pest problems and methods of control.

INTEGRATED PEST MANAGEMENT (IPM) is the evaluation and consolidation of all available techniques into a unified program to manage pest populations so that economic damage is avoided and adverse side effects on the environment are minimized. It involves determining means of modifying the life system of a pest to reduce its numbers to tolerable levels, applying biological knowledge and current technology to achieve the desired modification, and devising procedures for pest control suited to current technology and compatible with economic and environmental quality aspects. (For a discussion of IPM, with an emphasis on the United States, see Robert van den Bosch, "The Pesticide Problem," Environment, *May 1979.)*

Migratory Locust Program

The locust program at Weishan Lake, Shandong province, is typical of the efforts that have been made.[26] The physiography of the area was analyzed, and in the 1960s, with 40 million man-days of labor and 550 million cubic meters (m^3) of concrete, the landscape was transformed by building 423 irrigation systems with 21,552 ditches having a total length of 15,492 km. This system prevented flooding in 39,000 ha and resulted in a good harvest despite 100 rainless days. In 1973, 58,890 ha were planted with rice, and 8,190 ha around the rice fields were planted with shade, fruit, and medicinal trees. This program largely eliminated locust infestations in the region by destroying breeding areas. It also reclaimed thousands of hectares of arable land and improved the local environment.

Flight behavior in the locust's solitary and migratory phases has been carefully analyzed. Most migratory locusts fly at 15–20 m height, and some cover 25 miles or more in a single flight. The female's flying speed is greater than that of the male. At 19°C the averages were 4.7 meters per second (m/sec) for males and 3.7 m/sec for females; at 29°C the figures were 7.4 m/sec for males and 5.0 m/sec for females. Females were found to outnumber males by 10-37 percent, and it is believed that females play the leading role in setting the course of the migration. Chinese entomologists believe that the reflection of moonlight from lakes and rivers is the positive phototropic response that guides locusts to the adjacent breeding grounds. They also believe that the migratory flights are triggered by the arousal of the mating instinct as a result of moonlight and other appropriate environmental conditions.[27]

Recorded locust plagues in China date back to 707 B.C. The first organized efforts in Chinese insect control were aimed at combating depredations of the locust. (Photo: USDA)

As an indication of the paucity of information in the Western world about Chinese insect control, B. P. Uvarov in his authoritative *Grasshoppers and Locusts* (1977) cites only eight Chinese references about *Locusta migratoria manilensis.*[28]

Biological Control

Biological control, a basic component of IPM programs, consists of introducing and encouraging natural enemies to regulate insect pest populations.[29] The natural enemies involved may be insect predators and parasitoids, as well as a variety of insect pathogens—bacteria, viruses, fungi, and nematodes.

Biological control has been widely and effectively used in China since the Cultural Revolution and has, in its various manifestations, become an integral and widely practiced component of IPM programs in the culture of cotton, corn, rice, fruit and vegetable crops, and forests.

The pink bollworm (shown here on a cotton boll) is capable of destroying whole fields of cotton. In China, an indigenous wasp which parasitizes overwintering pink bollworms is mass-reared and let loose in barns to destroy bollworms pupating in stored cotton seeds. (Photo: USDA)

The vigor of Chinese biological control efforts is apparent in the widely developed and effective programs for the culture and mass release of the hymenopterous parasitoids *Trichogramma* and *Anastatus*, in the practical utilization of coleopterous predators such as *Coccinella septempunctata*, and in microbial control with the bacterium *Bacillus thuringiensis* and its exotoxin, and with the fungus *Beauveria bassiana*. Much of the groundwork for the success of these programs was probably developed during the period of close association with the U.S.S.R. during the 1950s when many Chinese made extended visits to the Soviet Union.[30]

Trichogramma. Chinese entomologists have identified 12 species of these egg parasites, which are tiny wasps about 0.4 mm in length and weigh about 4 μ micrograms (μg).[31] *Trichogramma* have been characterized as living insecticides, since the adult female wasps have great mobility and highly developed searching capacity for the eggs of lepidopterous pests. Four species of *Trichogramma*, (*T. dendrolimi*, *T. australicum*, *T. ostrineae*, and *T. japonicum*) are mass-produced in special institute laboratories and communes.

The parasitic wasps are cultured on the large eggs of the giant silkworm moths or on the eggs of the rice moth. As many as 175 *Trichogramma* have been reared from a single giant silkworm egg, and the average is about 60.

In commercial production large numbers of giant silkworm cocoons are placed on an automated belt that is rotated to place newly emerged virgin female moths in a convenient position for collection. The moths are passed through an electric meat grinder, which squeezes out the intact eggs. These are stored and can be used over a period of time for parasitoid production. The eggs are cleaned, dried, and glued onto paper cards, either for immediate use or for short-term storage. The cards are placed in large glass cages or alternatively in outdoor cages containing literally millions of adult wasps, whose eggs are laid in the silkworm eggs on the cards.[32]

After parasitism of the eggs on the cards, the latter are ready for release at carefully calculated dosages. It is important that the emergence of the *Trichogramma* wasps from the egg cards coincides with the egg-laying patterns of the pests to be controlled. Release rates of *Trichogramma* in China are high compared with those used in previous attempts in other parts of the world, which undoubtedly contributes to the high degree of control obtained.

Several major insect pests are controlled with *Trichogramma*, which are an integral part of IPM strategies. European corn borer, *Ostrinia nubilalis*, in Jilin province was controlled by *Trichogramma* releases in programs that covered over 34,000 ha in 1974. The release rate was about 230,000 to 310,000 per ha at about 90 points per mou (1 mou = 0.066 ha) beginning just before the corn borer eggs were laid and during the peak egg-laying period. The cost was stated to be slightly more than 2 yuan per ha.[33]

Trichogramma also play an important part in IPM programs for managing the pink bollworm, *Pectinophora gossypiella*; the sugarcane borer, *Diatraea saccharalis*; rice leaf roller, *Cnaphlocrocis medinalis*; the spiny pine caterpillar, *Dendrolimus sibericus*; and other lepidopterous pests. A high degree of technology has been developed for the rearing and mass release of the four important species of *Trichogramma*.

The generally successful results come from suitable production and release methods, adequate short-term prognosis of weather conditions and target insect status, and use of the most effective *Trichogramma* species or strain for the area and crop involved. In general, stable control as good as or better than that from the use of chemical insecticides was reported.

Obviously, the successful use of *Trichogramma* is incompatible with the regular usage of broad-spectrum insecticides. The successful employment of *Trichogramma* in Guangdong province, for example, has cut insecticide usage by half or more. This was reported to be welcomed enthusiastically by farm workers because personal hazard from pesticide poisoning was substantially reduced.[34]

Coccinella septempunctata. This large and aggressive ladybird beetle has been widely transferred from natural vegetation into cotton and citrus for the control of aphids and leaf roll[illegible]

Dibrachys cavus. This indig[illegible]us wasp parasitizes overwintering pink bollworms and has been mass-reared and liberated in barns in Shanghai and Shaanxi province to control pink bollworms pupating in stored cotton seeds.[35]

Use of this parasite has been an important part of the cotton IPM program.

Ducklings. A particularly innovative program of biological control using young ducklings as predators has been developed by the Zhongshan University Institute of Entomology. Ducklings are herded through rice fields in flocks of 1,000 or more and voraciously consume a variety of rice pests, including the rice grasshopper, the brown plant hopper, green rice leafhopper, and the rice stem borer.

Although this is an ancient Chinese practice, it is supported by meticulous research on predator/prey ratios and duck biology. For example, a single hungry duckling was found to consume about 200 insects per hour. In the Daxia Commune of Guangdong province, about 3,900 ha of rice are protected each year by about 220,000 ducks that are herded through the early rice crop by 853 duckherders. The pest population is reduced by 65-70 percent. This basic program is supplemented by the liberal use of *Trichogramma* and *Bacillus thuringiensis.*

The amount of insecticides applied on early rice decreased from 75,427 kg in 1972 to 34,112 kg in 1974 and to only about 6,700 kg in 1975. This program is very popular with peasants working in the field, who strongly prefer a pesticide-free environment, and presumably with the ducks as well.[36]

Microbial controls. The utilization of insect diseases in control programs is practiced on a large scale in China. Millions of metric tons of formulations of the spore-forming bacterium *Bacillus thuringiensis* (BT) are applied to rice, corn, cotton, vegetables, and forests for the control of lepidopterous larvae. BT is produced by both liquid fermentation and semisolid lower-yield fermentation methods using damp peanut and soybean meal in shallow baskets. The latter is cheaper and better suited to local commune production, and the output is standardized by testing before use.

BT applications were stated to produce 90-100 percent kill of pine caterpillar and 80-100 percent kill of cabbage armyworm, *Barathra brassicae.* BT is highly compatible with other biological control methods, such as mass release of *Trichogramma*, and because of its safety, is popular with peasants.

The fungus *Beauveria bassiana* has been described for many years as a possible microbial control, but its use has not been developed in the West. However, a strain attacking the European corn borer has been successfully used in Jilin province in conjunction with *Trichogramma* on more than 60,000 ha.[37]

The fungus is cultured in flasks, crocks, or shallow pits in the ground, using wheat and rice bran as the culture medium. *Beauveria bassiana* is applied as a granular or powdered product to piles of corn stalks and stubble collected in the fall to kill the overwintering larvae and to the tassels and silks of the summer crop. The control obtained was described as 83-96 percent for the overwintering larvae and 80-90 percent for the spring generation.[38]

Hungry ducklings, herded through rice fields in flocks of 1,000 or more, voraciously consume a variety of rice pests. It has been found that a single duckling consumes about 200 insects per hour. (Photo: H. Beemer, Jr.)

Among other approaches, nuclear polyhedrosis viruses (NPV) are being developed for the control of such pests as tussock moth, the cotton leafworm, and cabbage caterpillars.

Light Traps

Insect forecasting and control in China involves the use of light traps on a scale much greater than that in any other country. In Hunan province there are said to be about one million "blacklight" traps in an area of about 210,500 km^2. Networks of electric power lines intersect the rice fields. At night the eerie blue-violet glow of numerous blacklight traps was visible from the train traveling between Changsha and Guangzhou. The spacing of these blacklight traps varies from one trap per 1 to 2 ha in Jiangsu province, one trap per 2 to 3 ha in Guangdong province, and one trap per 3 to 4 ha in Hunan province.

A variety of traps were seen; all consisted of a 20-watt fluorescent tube emitting a continuous spectrum of light from 300 to 500 nanometers (nm), but with peak emission at 365 nm.[39] The fluorescent tube is centered between four vanes of glass, and the whole apparatus is commonly mounted over a permanent brick water basin or bucket. The water basin usually contains sticky rice water to trap the stunned insects, and the nutritious gruel thus obtained is fed to fish or hogs. For forecasting, electric grids or cyanide jars were used as the killing device beneath the fluorescent tube.

The development of these blacklight traps was apparently the result of careful study of the response of night-flying lepidoptera to monochromatic light. Ting et al. studied the phototactic response of cotton bollworms to 13 monochromatic lights ranging from 333 to 656 nm.[40] The 333-nm light was most attractive to the bollworms, but armyworm adults responded best to 375 nm. At the Nantong Institute of Agriculture, the attractive power of 20-watt blacklight traps and 200-watt incandescent traps was evaluated. During 1973 a combination of the two light sources caught 63,097 destructive insects compared with 11,035 by the blacklight alone.[41]

Insecticides

The origin of the use of indigenous Chinese plants containing insecticidal constituents is lost in the mists of 5,000 years. However, their use was extensive in pre-Revolutionary China and continues

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Intensive ecological study has led to complete abandonment of broad-spectrum insecticides such as DDT in Chinese agriculture. There is now almost no aerial spraying. The Chinese are currently attempting to develop procedures for the use of pesticides within a sound ecological framework. (Photo: H. Baemer, Jr.)

to be substantial today. In 1958 over 500 native plant and mineral products were processed into more than 10 million tons of insecticides and fungicides.[42] Among the principal products derived from native plants were alkaloids such as nicotine from *Nicotiana* species, anabasine from *Anabasis aphylla*, rotenoids from *Derris* species, and extractives from *Kalanchoe* (effective against aphids) and garlic. Research in this area is still continuing, and in conjunction with the renewed interest in Chinese medicinal plants, useful discoveries may be made.[43]

Following World War II, the worldwide publicity given to organochlorine insecticides, such as DDT, BHC, and other new synthetic organic insecticides, had an immense impact on pest control in China. Domestic production of DDT and BHC began after 1949, and about 60 million kg of BHC and 4.3 million kg of DDT were produced in 1958. The introduction of BHC was especially rapid and increased by 11,000 percent between 1952 and 1958. It was used throughout China for the control of major pests. Airplane applications were widely used for control of the migratory locust; between 1954 and 1958 more than 5.0 million ha of crops were saved from locust outbreaks in this way.[44]

At first this widespread use of the organochlorines was widely acclaimed. In 1963, Tsien-hsi Cheng said that "the mass production and wide application of BHC is a milestone in the history of Chinese agriculture." However, further usage in China produced the same series of problems as found elsewhere in the world—widespread insect pest resistance, development of secondary pests into major pest problems, and environmental pollution. By 1975 the use of BHC and DDT was rapidly being phased out and was no longer permitted on fruits and vegetables.[45]

Early in the 1950s a national decision was made not to produce the cyclodiene insecticides (aldrin, dieldrin, heptachlor, endrin, and chlordane) for agricultural use because of their long-term persistence and environmental toxicity. Small amounts of chlordane and mirex are still used for termite control in soil and timbers. Toxaphene is used in China in a limited way to control bollworms, but its use is forbidden near rice paddies and fish ponds because of its high toxicity to fish. The independent Chinese experience with the persistent organochlorine insecticides is particularly interesting in view of the controversy produced by their regulation and ban in many Western countries.

Organophosphorus insecticides are the basic synthetic insecticides in use in China, and more than 30 different compounds are produced commercially. The emphasis today is entirely on organophosphorus insecticides of low mammalian toxicity.

Trichlorfon, introduced in 1957, is apparently the insecticide produced on the largest scale in China today.[46] It is publicized as the "enemy of a hundred worms." Its popularity is due to its safety, lack of persistence, specificity against chewing pests, and environmental degradability. Trichlorfon is the main deterrent against chewing insects in IPM programs in cotton and rice, and on cabbage and other vegetables, and deciduous fruits. The order of production and use of organophosphorus insecticides has been described as trichlorfon, dichlorvos, dimethoate, phosmet, fenitrothion, phosphamidon, and malathion.[47]

Ecological Issues

Insecticide resistance has proved as vexatious in China as elsewhere. The housefly and numerous species of mosquitoes have become resistant to DDT and BHC, and to various organophosphorus insecticides, as have the fruit-tree red spider mite, the cotton aphid, the paddy borer, and the rice leafhopper.

Impressive efforts are being made to delay the onset of insect pest resistance by alternating insecticide treatments on apples and citrus; three to five different insecticides are used in rotation. Determinations of resistance and cross-resistance are given high priority. However, the prevailing scientific attitude about resistance is pessimistic, and the increase in the resistance problem is a major factor in encouraging pest management programs.

Experience in China with the widespread use of broad-spectrum insecticides has been generally unfavorable, partly because of the emergence of secondary pests. The experience with deciduous fruits has been typical. The early use of DDT gave good control of a wide variety of leaf rollers, but nearly eliminated the natural enemies of many pests, including red spider mites. The mites were controlled with parathion at first, but rapidly became resistant. The use of insecticides increased until they accounted for 25 percent of the production cost of the fruit. The leaf roller, *Leucoptera scitella*, became a

rampant secondary pest.

Intensive ecological study led to complete abandonment of broad-spectrum insecticides and to the development of a pest management program emphasizing: orchard sanitation; hand-picking of overwintering cocoons; interplanting orchards with legumes to encourage the ladybird beetle, *Coccinella septempunctata*, and other predators as well as the parasite *Aphytis proctia*; together with selective spraying using lime sulfur, trichlorfon, and chlordimeform.[49]

There is much concern in China about the overall effects of the intensive use of pesticides on human health and environmental quality. The use of such highly toxic insecticides as parathion and methyl parathion is very closely regulated, and handling is limited to highly trained and experienced personnel. The Ministry of Agriculture has established strict rules about application equipment, protective masks and clothing, and the availability of antidotes.

New insecticides that have adverse health and environmental properties must have governmental approval before use. An Institute of Environmental Protection was established in Beijing in 1978, and a national system of pesticide residue tolerances is being developed along with a system of restricted periods between application and harvest.

Insecticides play important roles in China's pest management programs, in its remarkable progress in producing food for more than one-fifth of the world's population, and in its exceptional standards of hygiene and public health. More than 100 individual insecticide compounds are produced commercially in China, and the government aims to become totally self-sufficient in this area.

The manifold disadvantages of the unrestricted use of broad-spectrum pesticides have been recognized, and efforts are being made to develop procedures for the judicious use of insecticides in a sound ecological framework. There is almost no aerial application of insecticides; selective treatment of hot spots of infestation in field or orchard is the general rule. Biological and cultural control measures are used wherever feasible, and supplemental insecticide controls are planned so as to be minimally disruptive to the total ecology of field, orchard, and forest.

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THE HUMAN COSTS OF DEVELOPMENT

BY JAMES RUSSELL McGOODWIN

ANTICIPATING THE CONCLUSION of the Third United Nations Conference on the Law of the Sea (UNCLOS III) in 1975, 80 coastal nations extended their jurisdictional claims over ocean economic resources to 200 nautical miles from their shores. Most of these countries are enthusiastically promoting new maritime developments, and in less developed countries (LDCs) the mood seems particularly bullish. Many of these nations—struggling with domestic food shortages and scarce capital for development—look to their fisheries as a source of protein-rich foods, and for substantial income from exports. However, before the LDCs surge ahead with the development of their fisheries, they need to consider the possible consequences of the strategies available to them, benefiting from the past experiences of other countries which have preceded them in fisheries development.

Timely lessons may be drawn from the fisheries-development experiences of Brazil, Thailand, and Japan; but the development of Mexico's shrimp industry on the Pacific coast provides a particularly instructive case.[1] The growth of its shrimp-export trade has been extraordinary, especially with regard to the income it has generated and the phenomenal quantities of capital it has accumulated. Crustaceans—not petroleum, cotton, sugar, or any other primary commodity—are Mexico's leading export item in terms of total value.[2] Today the state-instituted, urban-based industry boasts seven trawler fleets with more than 450 vessels; ten freezing, packing, and canning plants; two fisheries-research institutions; one shipyard; and two Mexican-owned importing corporations (chartered in the United States and located in San Diego, California). More than 94 percent of the industry's shrimp catch is exported—around 30,000 metric tons last year, which brought nearly $80 million in the international marketplace.[3]

The growth of the shrimp industry has not been without its problems, especially those stemming from its dependency upon the United States, which is the major buyer of its production. But there is also a poignant and relatively unknown chapter in the story of its growth: the decline of the inshore fisheries and the corresponding impoverishment of thousands of rural-coastal peoples. By and large, the plight of these peoples is relatively unknown outside of the regions they inhabit. But their situation demonstrates how the development of one export industry—in this case Mexico's Pacific shrimp industry—can work unforeseen hardships in certain rural enclaves, and illustrates some of the larger

problems created by the dependency of the LDCs upon the developed nations. Those involved in developing social and economic policy must become more aware of the ramifications created by the introduction of any new technology in a society

South Sinaloa: A Case in Point

Coastal lagoons, salt marshes, and estuaries are important features of Mexico's

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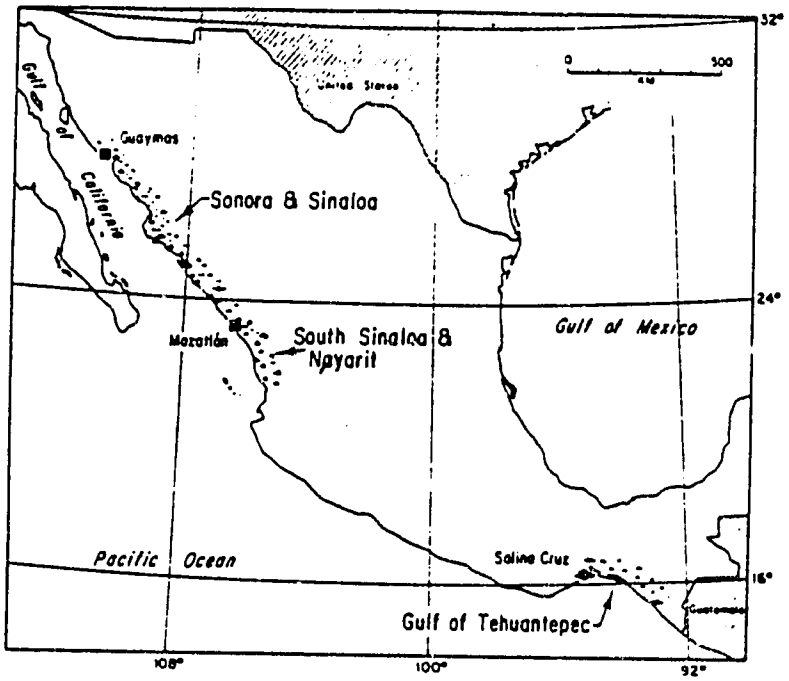
Pacific coast (see Map 1). These regions are the major inshore fisheries and the main rearing grounds for Mexico's commercially important species of shrimp. In former times they also produced great quantities of other seafoods, particularly oysters and fish.

Although this article focuses on the rural fisheries in the *municipio* [a legal unit similar to a U.S. county] of Escuinapa, south Sinaloa, the situation described for that region is duplicated to a greater or lesser extent in all of Pacific Mexico's rural-coastal fisheries. South Sinaloa is where today's shrimp-export industry had its beginnings, and in that region the social, economic, and political problems accompanying the growth of the industry have reached their point of greatest strain. Northward, among the lagoons and estuaries of Sonora, the rural population is relatively less dense, and southward, in the rural regions of the Gulf of Tehuantepec, the impact of the shrimp-export industry has been less severe. Nevertheless, living conditions in all of Pacific Mexico's rural-coastal regions are distressing.



MAP 1: Major Inshore Fisheries of Pacific Mexico.

In south Sinaloa average personal incomes of the region's household heads are less than $400 U.S. per year. Day-wage laborers in agriculture earn only about $2.50 U.S. per day when employed. Only 0.3 percent of the population has professional or technical training, and in the rural settlements less than two years of primary school is the mean educational level.

Most dwellings are crowded, squalid, and barren within, lacking sanitary facilities and running water. Fresh drinking water is always in short supply, and health and nutritional levels are extremely low. Infant mortality rates, moreover, are rising for the first time in decades, and the entire population is plagued by a variety of severe diseases—pervasive gastro-enteritis, amebiasis, and hepatitis, for example, as well as outbreaks of polio, tuberculosis, and rabies. In these hot and humid lowlands biting insects are also a problem.[4]

By and large, south Sinaloa's rural population owns or has access to very little productive land, so that the majority are dependent on whatever wages they can earn. More significant, however, is the fact that, in this region of extremely productive fisheries, food is often in short supply and much of the population suffers some form of nutritional disease. Only 2 percent of the total population are members of the government-instituted inshore fishing cooperatives, while the rest find their fishing activities severely constrained by laws reserving marine resources for the cooperatives.

The region's cooperatives, on the other hand, annually produce about 700 metric tons of shrimp—enough to provide every man, woman, and child with roughly 23 kilograms (more than 50 pounds) of that protein-rich food—but nearly 100 percent of that production is exported. And even the *cooperativistas* (members of the fishing cooperative), who have permission to harvest the region's seafoods, earn slightly under $700 U.S. per year.[5] Why, one wonders, are conditions so bad in these regions—the richest inshore fisheries of Pacific Mexico?

South Sinaloa's Coastal History

South Sinaloa's inshore fisheries were not always underdeveloped, nor were their human inhabitants as cut off from marine resources as they are today. Indeed, people have relied upon this region's rich coastal resources for at least 8,000 years, perhaps longer, and evidence of a considerable and long-term maritime history is clearly apparent to even a casual observer.[6]

The whole coastal region contains numerous shell mounds, some more than 3 kilometers long and 180 meters wide, with peaks reaching 11 meters. Not far from Escuinapa, head town of the *municipio* by that same name, archeologists have recently discovered a particularly large shell mound—a proto-pyramid, perhaps—21 meters high, quadrilateral in shape, and flat on top. Radiocarbon dating indicates that this structure was built about 2,000 years ago, suggesting the existence of coastal chiefdoms, and perhaps even nascent states, which subsisted upon the region's seafoods 16 centuries before the arrival of the Spanish conquerors.[7]

Estimates of the pre-Colombian population vary and are speculative, but some historians suggest that a relatively dense population inhabited the coastal plain at the time of the Conquest in the early 16th century.[8] Apparently, the Conquest-era aboriginal population was part of the Mesoamerican culture tradition, the same

OPPOSITE: Because rural houses around Teacapán, south Sinaloa, lack modern sanitary facilities, the inhabitants suffer a high incidence of nutritional, infectious, and parasitic diseases.

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as the Aztec and Maya. They built platform mounds and ball courts on the higher ground behind the coastal zone; they decorated their pottery in the Mesoamerican style; they grew corn, beans, and squash along the river courses; and they harvested and traded great quantities of seafoods from the estuaries and lagoons.

The conquest of south Sinaloa brought about the destruction of the aboriginal population. The Indians were victims of diseases introduced by the Spaniards, and their ranks were further reduced by a number of factors which were either non-existent, or at least not as severe, in other parts of Conquest-era Mexico. They had the misfortune of being conquered initially by Nuño de Guzmán, one of the era's most genocidal *conquistadores*. Soon thereafter, many were taken as slaves for the mines in the Sierra Madre Occidental, and for Cuba's sugar plantations. The scattered few who remained were pushed out of the region, displaced by the lords of cattle-raising *haciendas* which became common in this region. Indeed, the region was effectively depopulated of indigenous peoples by the 1750s, and today none inhabit the coastal zone.

For nearly three centuries thereafter the region was almost empty of human inhabitants, and its abundant marine resources went unexploited. Then, in the early to middle 19th century, a trickle of new settlers arrived—*mestizo* immigrants from other parts of Mexico. They settled the coastal lands that became available following Mexico's independence from Spain in 1821. Still more immigrants came after the French occupation in 1867.

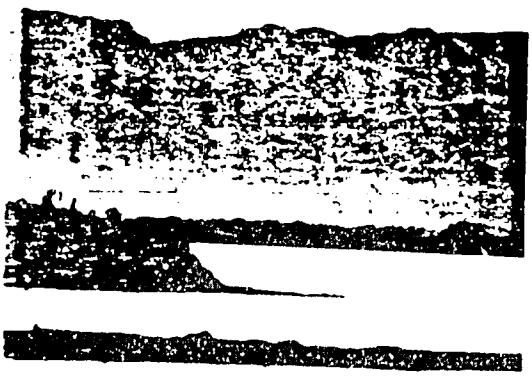
These new arrivals were quick to recognize the potential of the region's marine resources for subsistence and for commerce, and soon south Sinaloa's smoked oysters and salted shrimp were carried by muleteers across the Sierra to Durango and southward toward Guadalajara and Mexico City.

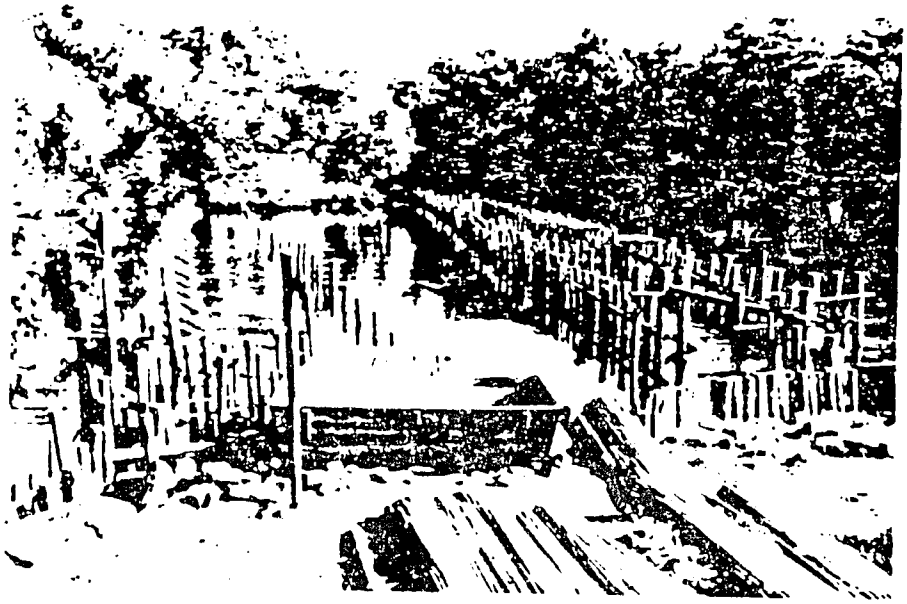
The landmark event for these fisheries occurred in the early 1870s when Chinese immigrants from Mazatlán visited the region around Escuinapa, bought large quantities of shrimp and oysters, and began to sell these to buyers from the United States, China, and Japan. In this manner, south Sinaloa's inshore fisheries made their debut in the international marketplace.[9]

By the outbreak of the Revolution in 1910, serious conflicts had arisen over the region's marine resources. The Diaz administration granted exclusive fishing rights to a number of small companies and limited subsistence fishing to regional fishermen not employed by the companies. During the Revolution, the brief Madero administration declared that subsistence fishing activities would be "free," and not subject to regulation.[10]

Today subsistence fishermen are still identified as *pescadores libres*, but now the term has a pejorative, criminal connotation, especially among fishing-industry officials, who use the term to refer to fishermen who are not members of the state-sanctioned rural-fishing cooperatives. Theoretically, subsistence fishing is still "free," but in actual practice it is greatly encumbered by various regulations that forbid shrimp harvesting for much of the year, or that prohibit such fishing in territories exclusively reserved for the cooperatives.

By the end of the Revolution, vessels from Japan and the United States were actively shrimp trawling along Mexico's Pacific coast. Mexico was powerless to prevent such incursions at that time: moreover, it lacked sufficient capital to finance the construction of its own vessels. Instead, it attempted to regulate and tax the foreigners fishing offshore,





This weir (called a *tapo*), which belongs to an inshore fishing cooperative on the El Mezcal estuary, south Sinaloa, is not in production. Its fencing has been rolled up and placed on the shore (foreground) so it will not rot. Rudimentary weirs such as these were the main technological items facilitating the beginnings of Mexico's Pacific shrimp industry in the 1930s.

"Pescadores libres"—subsistence fishermen.

while developing its own shrimp-export industry in its inshore fisheries.

Offshore, the Japanese eventually gained pre-eminence in the international shrimp market and drove their competitors from Mexico's Pacific coast by the middle 1930s. However, on the eve of World War II in 1939, fearing for the safety of its vessels so far from home, Japan abruptly withdrew its fleets from the area. Now at last Mexico had decisive control over all of its Pacific shrimp fisheries, and at this juncture it began to develop its own offshore fleets.

The Cooperatives

Mexico had already developed a system of state-instituted, inshore fishing cooperatives and central packing plants. Shortly after the Revolution, the Pacific's lagoonal and estuarial regions were declared federal territories. Then, with passage of the *Ley General de Cooperativas* in 1933, the nation undertook development of the various "enterprises of State participation" which characterize its Pacific fishing industry today.[11] Producers' cooperatives were established in the rural areas, along with a number of central packing plants for export operations. The rural fishing cooperatives of south Sinaloa and the packing plant at Escuinapa were the first of their kind on the Pacific coast.

Nearly all of the capital committed for the development of these enterprises went toward the construction of the regional packing plants. Development of the inshore fishing cooperatives involved little more than granting exclusive fishing territories and the recruitment of rural fishermen. The rural cooperatives required only rudimentary and fairly inexpensive weirs, which were constructed of mangrove posts and erected across tidal channels.

The rural cooperatives were inextricably bound to the regional packing plants by the terms of their charters. They were required to turn over all their exportable production to these plants, and to accept payment at whatever price levels the federal government annually established. Only in the conduct of their own internal affairs were they allowed to act as autonomous entities. Initially, this was not a handicap to the rural *cooperativistas*: marine resources were plentiful, the new organizations accepted nearly all rural fishermen wishing to join, and prices were such that most fishermen greatly increased their incomes.

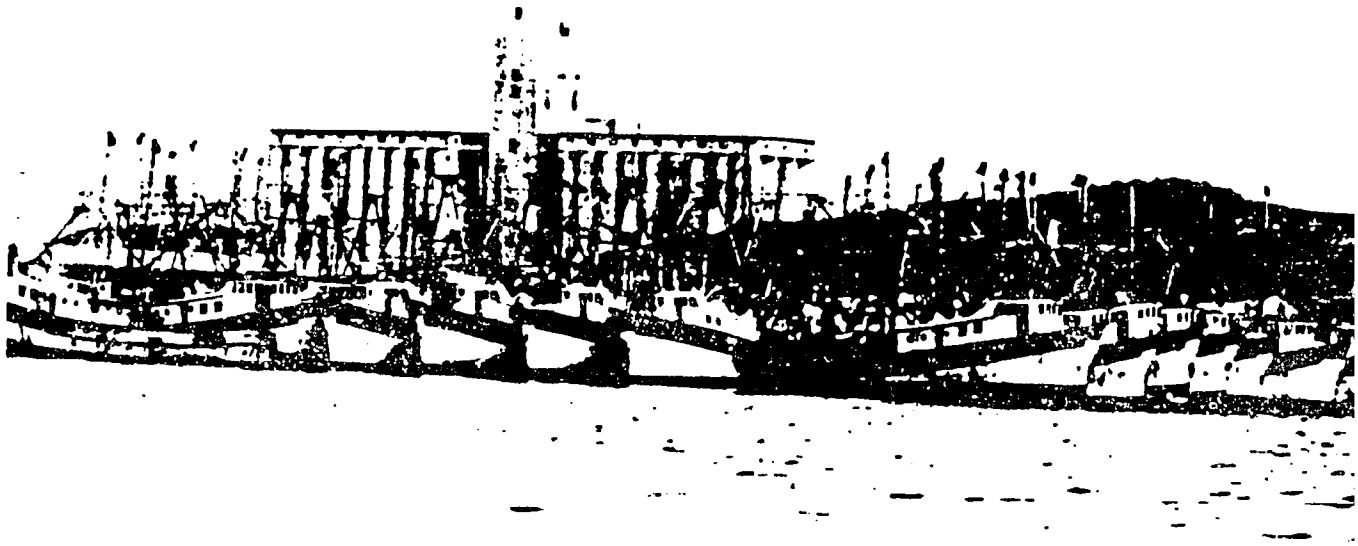
This was also the era of the establishment of the nation's agrarian *ejidos*,* and the rural fishing cooperatives were similarly hailed as important socio-economic reforms. Proponents claimed they would raise the standard of living of rural-coastal inhabitants and encourage wide participation in the fishing industry, and that the entire nation would benefit through the production of vitally needed foodstuffs and the generation of export income. In retrospect, however, it seems that the generation of export income was the main reason they were founded, for the other reform-oriented goals have eroded.

Social and Technological Problems

As economic entities, the rural cooperatives were fairly successful from the time of their inception through the middle 1960s, when Mexico's offshore shrimp-trawling industry finally overshadowed them. But long before that they had begun to suffer from serious problems.

Probably the most serious early problem was *caciquismo* (a corrupt, politi-

* Lands distributed to rural peasants as part of Mexico's post-revolutionary programs of land reform. Such lands are communally owned by a rural community; specific plots are assigned for an individual's use at no charge so long as he works the plot.



Shrimp trawlers with processing facilities in background, Guaymas, Sonora.

cal-economic bossism). During the Alemán administration, 1946-1952, *caciquismo* became widespread in the cooperatives, and it is still a problem in south Sinaloa. In many cases corrupt businessmen-politicians undertook to run the cooperatives for their own personal gain, relegating the *cooperativistas* to the status of mere shift laborers and denying them participation in the cooperatives' internal affairs—a right guaranteed in the organizations' charters. During that same period analogous situations arose on the nation's *ejidos*, particularly those producing export items.[12]

Other serious problems surfaced. The federal government periodically appropriated lands and redistributed these to impoverished peasants (*campesinos*)—resettling many of these into Sinaloa from other parts of the nation. South Sinaloa's rural-coastal population boomed, growing from around 8,000 persons in 1935 to nearly 31,000 in 1970.[13] As a result, competition for local marine resources intensified. Eventually the rural fishing cooperatives became entrenched economic entities, serving only a minority of the rural-coastal population. Internally, the cooperative also suffered from the effects of population growth, since membership rights could be inherited by members' descendants. Today south Sinaloa's cooperatives have more members than they need, and incomes must be shared with many marginally productive members.

Thus, by the early 1950s, south Sinaloa's rural-coastal population began to suffer serious strains, and the situation was greatly aggravated by the introduction of outboard motors and nylon nets into the fishery at that time. The use of outboard motors with large dugout canoes eased the transport of very large nets, while the nylon nets themselves, because they are nearly invisible underwater, proved disastrously effective in catching fish.

By that time most of the region's shrimp and oyster production was being sent abroad, so the fish which existed in great abundance in the estuaries and lagoons—snappers, snooks, drumfishes, mullets, and so forth—became the new mainstays of domestic consumption. However, the nylon nets quickly ravaged the inshore fish stocks, reducing them to very low levels within only a few years. Rural fishermen speak of former times, before the introduction of the motors and nets, when the surface waters of the lagoons sometimes appeared red from the shoals of snappers congregated there. Continued fishing pressure prevents the recovery of these resources, and today's net fishermen rely upon secondary species—so-called trash fish—which are converted into fish meal, a high-protein dietary supplement for poultry and livestock.

Why was the drastic over-harvesting of these prodigious fish stocks not prevented by the federal government, since it is empowered to regulate these fisheries? One reason may be that the fish, however important as domestic foodstuffs, were the major predators upon the region's shrimp stocks.

Other factors also contributed to the rapid decline of south Sinaloa's fisheries. Natural catastrophes, for instance, have played a part. In 1967 during the fall rainy season, a particularly severe flood buried the region's oyster beds under tons of silt, causing an almost total loss of that resource. Such floods have happened before in the region, at times with devastating consequences. Another flood in about 1300 A.D. similarly destroyed the region's oyster beds, forcing the partial abandonment of the fishery for a number of years thereafter.[14] Following the flood in 1967, the federal government imposed a moratorium on oyster harvesting and attempted to reestablish the beds; but its efforts have been only partly successful because the reduced oyster stocks have been subject to heavy pressure by rural *campesinos*, who illegally harvest them in order to provide food for their families. The oysters have also been damaged by contaminants—chemical pesticides mostly—used in the region's agricultural sector.

Offshore Trawling

Overshadowing all these disasters, however, has been the government's development of offshore trawling. The

development of the trawling industry has brought about a parallel underdevelopment of the inshore fisheries. To understand why, it is necessary to comprehend the life cycle of Pacific Mexico's commercially important species of shrimp, all members of the *Penaeid* family.

In simplest terms, the shrimp are hatched from fertilized eggs in the open sea, and then, in the form of microscopically small larvae, they migrate up coastal estuaries and into briny lagoons. In those delicate environments they spend some months, growing to what would be recognizable as juvenile shrimps. Finally, they migrate back to the sea, reach their maximal size, and eventually spawn, thus completing their life cycle.[15] Their seaward migration is particularly intense during the fall rainy season, when the influx of fresh water greatly reduces the salinity of the lagoons, and it is this movement on which inshore fishermen have relied for millennia.

From the perspective of Mexico's offshore shrimp-exporting sector and the marine biologists and fisheries managers who advise it, harvesting shrimp while they inhabit the inshore waters is regarded as poor practice. Inshore harvesting takes the shrimp out of the ecosystem before they have a chance to spawn, which threatens the ability of the resource to recover rapidly. Also, by removing the shrimp before they reach adult size, the ecosystem's maximum potential shrimp biomass is not produced. Furthermore, the large adult shrimp caught offshore bring higher prices per unit of weight in the international marketplace. Finally, harvesting shrimp with trawlers is less costly and far more productive than the low-yield, labor-intensive methods employed by inshore fishermen.[16]

Thus, as Mexico pursued the development of shrimp-export trade in this century, it progressively curtailed the inshore shrimp harvest, dissociating the rural population from a resource that had been central to their subsistence and commerce.

Production figures for 1950-1970 for the Pacific's offshore sector and also for south Sinaloa's major inshore cooperative indicate the dramatic increase in offshore production and the correspondingly dramatic decrease in production inshore (see Figure 1). Today the government permits south Sinaloa's rural cooperatives to harvest shrimp for only 10 to 12 weeks per year, whereas the voracious offshore trawlers are allowed 35 to 40 weeks of production annually.

Other factors are indicative of the stressful quality of life in this rural-coastal areas. Ongoing conflicts among landowners, landless *campesinos*, and *ejidatarios* (small-scale farmers who work on *ejido* lands) occasionally prompt group actions and violence similar to the highly publicized incidents which occurred in northern Sinaloa around the time of the last presidential succession. Severe conflicts also exist over rights to regional marine resources. *Campesinos* in the rural settlements sometimes shoot at the cooperatives' trucks—especially at night—as the vehicles pass through the countryside on their journeys between the lagoonal weirs and the packing plant. *Campesinos* engaged in subsistence fishing are sometimes arrested by soldiers from the *Infantería Marina* (the Mexican Navy's infantry), who are deployed in the fisheries during the fall shrimp harvest to enforce the cooperative's exclusive rights. Such enforcement measures have been only partly successful, however, because of the rural fishermen's dispersion in the labyrinthian systems of estuaries and lagoons. A few large-scale shrimp contrabanders also seem to operate with relative impunity, perhaps buying their security.

South Sinaloa's rural fishermen are not ignorant of the events which have marginalized their traditional way of life. Often, in the context of discussions concerning the development of offshore trawling, they exclaim, "*Camarón que duerme se la lleva la marea*" ("A shrimp that sleeps is taken by the tide"). The statement is an ironic, self-conscious acknowledgement of their socio-political dormancy as well as their inability to stem the tide of events which has impoverished them.

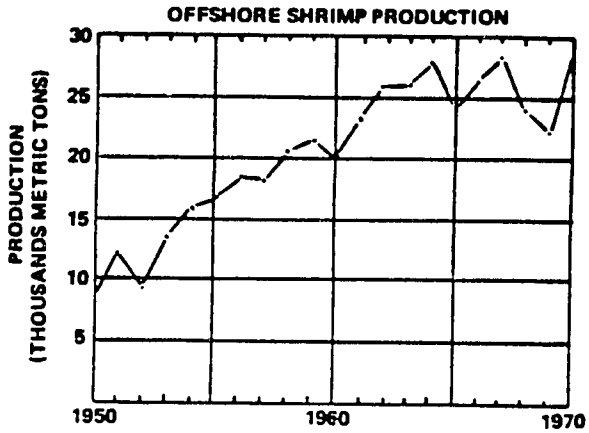
Current Policy

It would be glib to conclude that the negative consequences of developing Pacific Mexico's shrimp-export industry could have been easily avoided. Hindsight is always clearer than foresight. When today's shrimp-export industry was first organized, the nation was badly in need of capital to finance its reconstruction, and, at least initially, the inshore fishing cooperatives did elevate the standard of living in the rural-coastal areas. In 1933 the post-Revolutionary leaders could not have foreseen the great population growth to come and, given the nation's preoccupation with its agricultural sector and a lack of interest in the cultural traditions of the inshore fishermen, these reformers should not be blamed for emphasizing the development of shrimp exports.

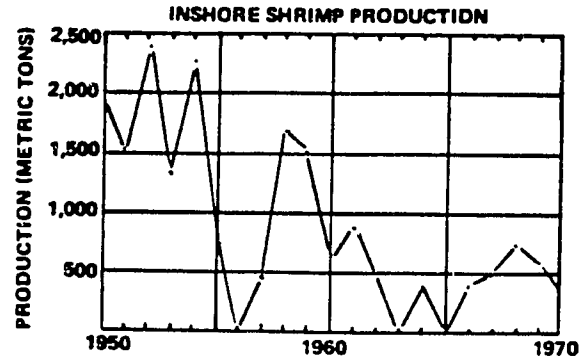
But Mexico is now experiencing acute and widespread food shortages, rising infant mortality rates, and an exodus of its rural poor to its crowded cities and to the United States.[17] Nevertheless, the federal government continues to announce plans to further develop its shrimp-export industry, despite increasing evidence that the industry has already reached the limits of its growth. Shrimp stocks have been declining for a number of years.[18] Some industry entrepreneurs question the evidence, pointing out steady production increases over the past decade; but the industry's own fisheries biologists counter that such increases only reflect the annual addition of new trawlers to the fleets. Various methods for increasing shrimp stocks are still being tried. The most important involves dredging projects which would facilitate the shrimp migrations between offshore and inshore waters; but these do not promise to make a significant difference over the long run.

Furthermore, since the industry exports nearly all of its production, its dependency upon the international market—and especially the United States, its major customer—often places it in a precarious economic position. In 1971, for example, the United States' unilateral imposition of a 10 percent surcharge on import tariffs precipitated an economic crisis having painful ramifications throughout Mexico's shrimp industry. President Echeverría responded by courting other foreign buyers for Mexican shrimp, particularly the Japanese, promising he would "weaken the embrace of the North," but such actions were futile.[19] The United States is still the major purchaser of Mexico's shrimp exports, and the industry is still highly

FIGURE 1. Shrimp production in Pacific Mexico, 1950-1970.



Annual offshore shrimp production for Mexico's Pacific coast. Offshore production rose almost 300 percent during the twenty years, 1950-1970. SOURCE: Instituto de Pesca, Mexico, D.F.



* Mexico imposed a moratorium on production in these years.

Annual shrimp production of south Sinaloa's major inshore fishing cooperative. Inshore shrimp production dropped from a high of 2,400 metric tons in 1952 to a low of 400 metric tons in 1970. SOURCE: Mendoza von Borstel, Xavier, Mem. IV. Congr. Nac. Oceanografia (Mexico): 407-418, 1972.

vulnerable to the vagaries of the international marketplace.

Dependency upon the international market has also caused the industry to engage in market behavior which seems indefensible for a nation experiencing food shortages. In spring 1978, for example, stories appeared in the nation's press reporting the destruction of large quantities of seafood in order to drive up its price in the international market. In the same period domestic food supplies were reported scarcer than ever. Those resources might instead have been distributed to ultimate consumers in food-deficient regions.

Mexico needs to seriously reconsider its policies for the management and development of its Pacific-coastal fisheries. It should stress revitalization of the inshore fisheries, encourage the resurgence of inshore fish stocks, and relax its restrictions upon individualistic subsistence fishermen and small-scale regional commerce. Positive steps should also be taken to invigorate the nation's domestic seafood markets.

Such a change of policy might not be as radical as it first seems. Indeed, it may come about naturally as increased exports of petroleum from the Campeche Bank appreciate the *peso*, thus reducing the relative profitability of shrimp exports. Perhaps then the nation will not have to rely as heavily as it has in the past upon the export of an important food commodity.

Few LDCs are fortunate enough to have huge undeveloped reserves of energy resources, but they—and those countries and international agencies which are assisting them—could learn much from the development of Mexico's shrimp-export industry. The Philippines, for example, has both rich shrimp resources and a large, traditional, rural-coastal fishing population, and that nation is now actively developing its fisheries. Having established a 200-mile offshore economic zone, the Philippines—like many other coastal LDCs—is being lured by the export income which certain seafoods promise. Unfortunately, many LDCs ignore the poverty of their rural-coastal regions, viewing that and the development of their fisheries as distinct, or unrelated, problems. Here the work of anthropologists, ethnohistorians, rural sociologists, and economists could inform the course of these nations' future fisheries' development.[20]

Fishing is a small part of the GNP in most countries. Even in Japan, a nation well known for its extensive fisheries and fishing traditions, the value of agricultural output exceeds that of fishing by 50 times.[21] As a result of its relatively small role in most nations, fisheries are often not well understood as a socio-economic phenomenon. This may lead national economic planners to lump various forms of fishing under one rubric, so that they fail to distinguish crucial differences between subsistence versus commercial fishing, or inshore versus offshore fishing. Moreover, many nations may not be sufficiently aware—because they lack the appropriate information—that increased income from fisheries' exports may, in some cases, be more than offset by the consequent social and economic costs in their rural-coastal zones.

These considerations, as well as the undesirability of economic dependence on foreign markets, suggest that LDCs should exercise great caution when planning to develop fishing industries predicated on the production of income from exports. Moreover, the participation of their own rural poor in fisheries development should, as a matter of policy, be given at least equal importance with the possible income the fisheries can generate.

NOTES

1. See James Russell McGoodwin, Fisheries Policy and the Underdevelopment of Inshore Pacific Mexico, Woods Hole Oceanographic Institution, Technical Report 79-44, 1979, p. 6; also, by the same author, "The Decline of Mexico's Pacific Inshore Fisheries," Oceanus 22 (1979): 52.

2. Food and Agriculture Organization, Trade Yearbook 1972, FAO, Rome, 1972: United Nations, Economic Survey of Latin America 1972, U.N., New York, 1972.

3. Centro de Estudios Políticos Económicos y Sociales, Síntesis Estatal 1968-1978, and Jornades de Información y Estudio para la Programamación del Desarollo de Sinaloa 1968-1978, Centro de Estudios Políticos Económicos y Sociales, Culiacán, Sinaloa, 1968-1978 (annual reports).

4. Manuel Casas Pérez and Gabriel Rodriquez Salgado, Estudio para el Financiamiento Agropecuario en la Zona Sur de Sinaloa, Banco Agropecuario, Mexico, D. F., 1967.

5. Note 3 above.

6. Carl I. Hubbs and Gunnar I. Roden, "Oceanography and Marine Life Along the Pacific Coast of Middle America," in Robert C. West, ed., Handbook of Middle American Indians, Volume 1, Univ. of Texas Press, Austin, 1964.

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Sociological Perspectives on Energy and Rural Development: A Review of Major Frameworks for Research on Developing Countries[1]

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ABSTRACT The contemporary energy situation raises new problems for rural development which require fresh thinking and perhaps some reorientation by sociologists. Five major frameworks for the sociological analysis of energy-rural development interactions in developing countries are critically evaluated. The frameworks are appraised in terms of their conceptualization of energy and its social significance, and the sociological variables emphasized. It is argued that despite the relative unfamiliarity of energy to many sociologists, an uncritical acceptance of the models, concepts, and assumptions of technological perspectives on energy is unwarranted. Energy reductionism, in particular, is a technological imperative that can have a very significant impact on the characteristics of sociological analysis.

Introduction

Broader awareness of the energy trap to which most societies have become vulnerable has peaked in recent years for obvious reasons. Among industrial societies, dramatic escalations in prices, shortages in supplies of hydrocarbon products, and heightened concern for the exhaustibility of improperly-managed natural resources have combined to create a sense of "crisis" in some sectors. While work on the American food system has pointed to its high energy intensity (Buttel and Larson, 1979; Desai, 1977; Pimentel *et al.*, 1973; Steinhart and Steinhart, 1974) and recent agenda for basic agricultural research reflect sensitivity to petroleum dependence problems (National Academy of Sciences, 1977; Oyer, 1976; Wittwer, 1978), other research has suggested that in biomass productivity terms the American agricultural system is highly efficient (Pasour and Bullock, 1977; Revelle, 1979) and that agricultural energy problems are not serious because agricultural production represents only 3 percent of the nation's energy bill. Less affluent countries are much closer to the margin in meeting even basic human needs for significant proportions of their populations. They are much more heavily reliant on agriculture to generate income and employment in rural areas and to satisfy the

[1] An earlier version of this paper was presented at the 1979 annual meetings of the Rural Sociological Society in Burlington, Vermont. The authors wish to acknowledge the constructive reactions of John Bardach, George Beal, Ramesh Bhatia, Fred Buttel, Romir Chatterjee, John Holdren, Malcolm Slesser, and Terry Rambo, and the helpful suggestions of Stan Albrecht.

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often competing requirements for food and foreign exchange (Lappe and Collins, 1977). In these countries, the energy crisis is less a shock than another step down a blind alley. Over a generation, strategies to improve agricultural productivity and develop viable modes of non-agricultural rural employment have barely kept pace with population growth (Asian Development Bank, 1977). Furthermore, efforts to increase food production using high input cultivation regimes have revealed the land-energy trade-off which this usually involves—diminishing returns in protein per hectare year to intensified input applications (Slesser, 1973; Slesser *et al.*, 1977). In recent years, it has become clearer that the technological and institutional prerequisites of these developmental strategies may only be sustainable at increasingly higher cost in terms of resource requirements, regressive social impacts, and future inability to adapt (International Labor Organization, 1978; Koppel, 1978).

For many countries, a range of very complex energy policy questions are in varying stages of engagement (Resource Systems Institute, 1978). Most of those questions are beyond the scope of this paper, but a general awareness of their content will be assumed. What will be discussed here is the following issue: What frameworks should sociologists be using to understand the energy-rural development interface, especially in developing countries? The question is hardly academic. Rural sociologists will be asked to participate in judging the feasibility, appropriateness, and impact of various rural energy strategies in developing countries. The impetus will come from the Board for International Food and Agricultural Development (BIFAD) institutional strengthening grants, the Title XII program, strong interests within the Agency for International Development (AID) and emerging programs in the United States Department of Agriculture, just to name a few. Our purpose is to stimulate discussion which confronts many of the crucial uncertainties surrounding the social significance of energy issues.

The problem is stating the problem

Determining an appropriate analytical framework is a decision which reflects the central vision of the problem to be analyzed. If we review work accomplished to date on energy and rural development, the outlines of several visions can be discerned. Before discussing these in any detail, however, it will be useful to identify some common attributes of existing work on developing countries. The following critical conclusions can be drawn:

(1) *The work is overwhelmingly energy assessment.* The evaluation of specific technologies or tasks in net energy terms is carried out within the framework of a distinct "rural energy system." The utility of

"rural energy system" as a meaningful metaphor has not been evaluated. One consequence is that research is only occasionally oriented to contemporary agricultural development issues or to a broader conception of rural development.

(2) *Existing research has relied extensively on the aggregation of energy coefficients across a wide range of tasks and users.* This is a result, in part, of data constraints and can be considered a measurement problem. There are still very few carefully-executed household energy demand studies for low income families in rural areas, and there is considerable variation in the ways national energy statistics are generated, treated, and published.

A measurement problem, however, is often symptomatic of a basic conceptual problem. The focus on aggregation illustrates a measurement problem which follows from inadequate attention to the issue of energy indexing. It is commonly assumed in energy analysis that all kilocalories are equal. The assumption may be acceptable where only a single fuel is being measured, but when the analysis includes different types of fuels, as well as fuel production and consumption systems, the assumption is false and the comparisons of energy quantities misleading. The difficulty arises from the differences between work potential and work performed, an efficiency issue derived from the second law of thermodynamics. For example, one Kwh of electricity has far greater work potential than one Kwh (thermal) of coal. Does it follow that one Kwh of electricity represents "more" energy than one Kwh (thermal) of coal? Not necessarily. It might take three times as much energy resource to deliver one Kwh of electricity as it does to deliver a Kwh (thermal) of coal. "Like money, one does not expect a single number to tell one everything one needs to know" (Slesser, 1978).

Nevertheless, there is strong interest in developing a common metric based on some understanding about energy quality. An effort to reach such an understanding is problematic in part because thermodynamic limits on many energy conversion processes commonly used in rural areas have not been established. It is made even more complex by the linkage of the energy quality issue to institutional, economic, and even cultural factors. The energy indexing problem is extremely basic, but it should not be foreign to those sociologists who have employed the tools of systems analysis nor to those who have examined the generally high correlations between commercial energy consumption and urbanization. What the aggregative emphasis has ignored, with only a few exceptions (Bealer, 1980; Harris, *et al.*, 1980), is that within the same society several energy quality systems may be operating and that there may be significant relationships between overall

energy efficiency (not just commercial fuel consumption) and various modes of social organization.

(3) *That portion of existing research which is oriented to the consideration of policy options frames the choices, with few exceptions, as technological.* The technological imperative is evident in the principal social question normally raised: "What social changes are necessary to accomodate technological solutions to energy problems?" That type of question limits at the outset the alternatives which will be considered.

(4) *Rural sociologists and other social scientists concerned with rural development have taken, at best, only a minor role in conceiving, implementing, and analyzing rural energy research.* This situation reflects a basic institutional reality in most developing countries: It is not the rural development or agricultural research agencies that are in the rural energy policy arena; it is the recently created energy ministries that are engaging in explicit discussions of energy issues in rural areas.

Despite this rather unsatisfactory overall picture, several more positive aspects of existing research on energy and rural development can be noted. There is an increasing tendency to locate the rural energy question within the food-poverty syndrome (National Research Council of Thailand, 1979; Resource Systems Institute, 1979a, 1979b, 1980; Revelle, 1978; United Nations University, 1979). There also appears to be an emerging concern to moderate some of the more spectacular alarmist assumptions which have previously motivated much rural energy research. This moderating trend is characterized by more carefully-executed household and village studies, by occasionally specifying sociological variables as exogenous, and by giving more attention to the wide variation in rural energy mixes and rural energy end-uses (Bajracharya, 1980; Bhatia, 1977; Desai, 1978; Koppel, 1980; Makhijani and Poole, 1975; Smith *et al.*, 1980; Tyers and Revelle, 1978; Weingart, 1979b).

Our discussion now turns to a closer examination of the principal sociological frameworks which are represented, in one version or another, in existing work or, in our judgement, appear as strong candidates for utilization in future research. Our purpose is not to definitively introduce the frameworks to those unfamiliar with them nor to provide original interpretations of their characteristics for old hands. The purpose is much more limited, namely, to suggest what the frameworks have to say about energy. If our characterizations sometimes appear too general or tentative, it is because there are too few cases of clear application to support more categorical statements about how researchers using these frameworks are proceeding. In those cases, we are making appraisals based on likely attributes of framework application to rural energy questions.

Socio-technical analysis

This framework, developed principally within industrial and organizational sociology, is oriented to the decomposition of technological processes into basic tasks or components. Analysis focuses on the relationships of organizational and managerial characteristics to attributes of tasks and technological processes. The framework's application to rural energy analysis has been accelerated by the early popularity of the "flow" metaphor as an approach to understanding energy-rural development interactions. Energy was seen as "flowing" through rural systems. In the socio-technical framework, however, energy flows do not necessarily occur in a system integrated around some factor other than energy. Research concentrates on chains of agricultural and household energy uses.

Socio-technical analysis can provide a basis for translating characteristics of technological processes into social terms. Examples include research on cooking functions (Institute for Energy Research, 1978), crop drying (Chancellor, 1978), rice production (Kuether and Duff, 1979), and biological pest control (Kenmore, 1979). Socio-technical analysis can also be a useful basis for comparing alternate ways of performing the same task—for example, biogas generation (Santerre and Smith, 1980; Smith and Santerre, 1980). The major limitation of socio-technical analysis is that the rural social milieu tends to be present only in the form elicited by technological components or energy "flows." A rural energy "system" is assumed to be a meaningful entity. This assumption yields a reductionist vision of a social system, one in which the system exists only within a line-item energy account. Beyond the order supplied by the reconstitution of energy conversions into some technological process, the social system does not really exist.

Evolutionary perspectives

This framework seeks to identify systematic processes underlying the distribution of technologies and patterns of technology utilization across geographic and social space as well as across time. Perhaps the most familiar example to rural sociologists is diffusion research. One approach has been to use a diffusion framework in forecasting. Marchetti and Nakicenovic (1978), for example, studied the time frame and adoption pattern for large-scale changes in technology systems as a basis for forecasting rates of change in energy systems. Others have used similar procedures to generate forecasts of large-scale conversions to decentralized solar thermal and photovoltaic electricity systems and widespread use of biogas and biomass related energy technologies (Buffington and Zar, 1977; Electric Power Research Institute, 1978; Prasithrathsint, 1979; Weingart, 1979a). Such studies are useful ways of thinking in specific terms about alternate futures. The major limitation of the approach for energy analysis stems from

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a tendency to improperly generalize historical patterns of energy use and social change. Generalizations about renewable energy systems, for example, based on diffusion of non-renewable energy technologies often contain quite arbitrary assumptions about the variability of relative factor costs, risks, and externalities. The wise variation in basic estimates of coal and oil reserves, "proven" and "undiscovered," makes it difficult to properly characterize the diffusion characteristics of past patterns of energy resource depletion. For studies on rural areas of developing countries, attempts at extrapolation based on interpretations of agricultural technology diffusion studies may be premature. Agricultural technology diffusion studies have focused on the use of petrochemical inputs (such as nitrogenous fertilizer) and middle distillate products (such as kerosene). This gives an incomplete picture. What is missing is adequate attention to: (1) the complete fuel resource base available to and allocated by rural users, and (2) the complex intermediate roles played by technologies for fuel production and fuel consumption in linking energy sources and end-uses.

Another evolutionary perspective on the energy-rural development problem is a continuing tradition of anthropological and rural sociological research which can be broadly placed within the framework of White's energy and cultural development hypothesis (Adams, 1975; Buttel, 1977; Buttel and Larson, 1979; Cottrell, 1955; Shiels, 1972; Spicer, 1952; White, 1943, 1959). White's thesis basically posits a monotonic relationship between cultural complexity and aggregate energy consumption. Energy is assumed to be a critical limiting factor for cultural adaptation. White's (1959) thesis has motivated considerable research. Recent empirical work by Rambo (1979a, 1979b) refutes the linear hypothesis for *per capita* energy consumption. Further re-evaluation of White's hypothesis should yield interesting research on the relationships between changes in social scale and complexity and patterns and intensity of energy use. A major problem, however, for this version of evolutionary research is the misleading and possibly noncomparable indices that result from aggregating a wide range of energy uses and fuel types in terms of a single heat measure. The issue is the problem of energy indexing, which was discussed earlier. Energy indexing is not simply a measurement problem but a conceptual problem: what is energy? Analysis in the White tradition will need to find ways to resolve or circumvent the energy indexing problem.

Evolutionary research can be useful as an approach to comparative analysis and as a basis for stating and verifying a limited set of basic energy-social organization typologies. The utility of the framework for rural energy research, however, ultimately rests on the vision of "what" is evolving and "what" if anything is being replaced, modified, or recast. It follows that as there is clarification of what it is about

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energy that might be significant for rural social organization and what it is about rural social organization that might be significant for energy, evolutionary perspectives will have more to say about energy and rural development.

Dependency

This framework views the energy question in developing countries as an element of the international political economy. The energy-rural development issue is seen in the context of the dynamics of underdevelopment. Analyses of the "green revolution" generated within this framework focus on the inevitability of particular energy paths being imposed on developing countries (Lappe and Collins, 1977; Levinson *et al.*, 1977). Particular energy paths are "imposed" through the political organization of technology transfer, multilateral and bilateral aid, and foreign investment, as well as by the tendencies of developing country elites to identify with the political and economic elites of more developed states. Research conducted in this framework focuses on relationships between the powerlessness of the poor and the international division of labor. Such research tends to advocate disengagement from situations of constrained choice. The juxtaposition of "appropriate technology" research with the view that preferred energy futures for rural areas lie in self-contained village systems often occurs within the outlines of a dependency vision (Briscoe and Bari, 1979).

As a mode of social analysis, the dependency framework stands the socio-technical analysis framework on its head by looking to class, political, and other economic relations as the major factors characterizing social systems *and* determining energy choices. The focus on political interests should be important in future applications of this framework to rural energy issues. This focus will distinguish those who participate in energy-related decision-making from those who are affected by decisions about energy-related issues. Similarly, research conducted in this framework should illuminate the numerous aspects of urban-rural relationships which influence energy-rural development interactions, and the intersections of those relationships with class-related variables.

This framework, however, will have to overcome some debilitating over-simplifications. Fuller utilization of locally available renewable energy resources *may* require high technology and high knowledge inputs as least as much as local ingenuity. Biogas technology is an example. Some relationship to those parts of society and the international system able to provide needed inputs appears inescapable. It does not always follow that bondage accompanies such bonds. Determining when it doesn't rather than assuming it always does might lead to more discriminating analysis. Finally, the framework is limited

to the degree that it underestimates the scope for choice and experimentation present in most rural systems (Smith, 1979).

Social Impact Analysis

The application of this framework to energy-rural development issues is less the employment of a coherent conceptual framework than the utilization of an eclectic mix of elements from other frameworks. Social impact analysis tends in practice to be oriented principally to performance indicators; it is relatively unconcerned with directly identifying or understanding underlying dynamics. The major utility of social impact analysis for rural energy research is that it may encourage sensitivity to correlations between energy patterns and important rural development performance indicators such as employment, health, and income (Islam, 1978, 1979; National Electrification Authority of the Philippines, 1980). Moreover, social impact analyses are more understandable to policy-makers than most work coming from the other frameworks. The limitations of social impact analysis are similar to the limitations discussed for the diffusion brand of the evolutionary framework. Without an adequate theory of energy and rural social systems, generalization remains a formidable problem. To the extent, however, that such theory can be inductively derived, social impact analysis will probably be a major contributor.

Ecological Approaches

This is probably the leading candidate for preeminence in social research on energy and rural development, largely because it draws from a paradigm that encompasses both energy and social systems. Consequently we will discuss this framework in considerably more detail than the others.

Within the ecological framework, "the aim of energy analysis is to quantify the energy flows inherent in all systems" (Gilliland, 1977:1). Such analyses can occur at micro and macro levels:

> Micro analyses are generally restricted to specific or limited numbers of processes, tasks or technologies. That is, they involve analyses of small systems which can be defined precisely . . . Who can disagree with being able to compare the energy costs of various processes for producing the same product or service (Gilliland, 1977:2).

This leads to what has been called energy accounting, either through the intensive analysis of end-uses and energy mixes in small systems (Chatterjee, 1978) or analagous accounting in simplified representations of large systems (Brookhaven National Laboratory, 1978; Mubayi and Lee, 1977a, 1977b; Ramachandran and Gururaja, 1977). Where problems arise is in assigning quantitative energy values

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to non-physical or non-mechanical inputs such as labor, organization, or leadership, particularly in dealing with issues of second law efficiency in energy accounting.

At the macro level, ecological research issues are much more complex. What the ecological framework is doing at the macro level is attempting to construct an energy theory of value. The work of Odum (1971, 1975; Odum and Odum, 1976) is the key formulation for most social scientists. Odum presents a holistic perspective which purports to explain interactions among matter, energy, and money. Energy flow per unit of time (power) in an economy is the basic yardstick against which all social processes can be measured. Human values ultimately follow energy costs. Odum's vision is a central pillar of the emerging science of ecological energetics. This is a science, however, in which the dominating concepts are biological.

When applied to rural development, the ecological energetics framework results in analyses strongly framed around the accounting term "energy balance." This measure becomes the major criterion for evaluating the efficiency of alternative *social* arrangements (Phillipson, 1966; Revelle, 1979). What is often overlooked is that energy balances are best suited to relatively simple and closed *natural* ecosystems (Lee, 1969; Parrack, 1969; Rappaport, 1968, 1971). Extension to large, open, and complex social systems often leads to illustrations of energy reductionism. Ecological energetics takes a necessary condition for a social system, an environment congenial to biological (human) systems, and converts it into a determinant of optimal social systems. In small, isolated, and relatively undifferentiated social systems, the proposition may be defensible (although an analagous and equally compelling proposition might be that all history is caused by water). Most rural people, however, do not live in small, isolated, and relatively undifferentiated social units. Most rural people participate in and are influenced by a range of intermediate social structures, including patron-client arrangements, social class, and village systems. What is required are not the tools of biological system analysis borrowed by ecological energetics, but ecological metaphors that are unambiguously social.

Social ecology metaphors *are* available, which leads to the question of an "ecotopia"—or an ecological utopia. If social scientists in the United States and Asia seek an ecotopia—the realization of relatively small and autonomous social systems, sustainable and resilient because of favorable energy balances and positive relationships with a renewable resource environment (Revelle, 1979; Stivers, 1976; Watt, 1977), and able to satisfy the basic material and social needs of their populations—they stand in very different positions from which to approach that ecotopia. American rural society is part of an affluent, predominantly urban society. Agriculture is energy intensive, large scale, and heavily dependent on petroleum products; population

pressure is low; the processing of agricultural products constitutes a major component of the total food system; significant intermediate structures are present and strongly keyed to urban systems; and there is relatively high occupational and residential mobility. For the United States, key value and risk questions are:

(1) What quality of life standards can we maintain?
(2) What quality of life goals will need to be changed, dropped, or added?
(3) How will impacts be distributed?
(4) Through what processes and within which time frames can such a strategy be implemented?

Between Indonesia, Bangladesh, and the Philippines, there is wide variability, but there are some common differences compared to the United States. Considerable attention in the United States is given to increasing utilization of renewable resources, but rural systems in Asia and Africa have to deal with excessive dependence on such resources (Gamser, 1980; Tyers and Revelle, 1978). For some countries, the consumption of commercial fuel in rural areas is negligible; but there is growing evidence that damage to the recovery capabilities of natural ecosystems through over-exploitation (for example, of fuelwood resources) is certainly *not* negligible. If ecotopia in the American case can be characterized as a "return" to a more energy efficient and environmentally sound strategy, the transition to ecotopia for LDC's is a "transformation"—the attainment of a stable and continuing capability to satisfy basic social and material needs. Key value and risk questions become:

(1) How can different approaches to satisfying basic food needs be developed and implemented at the same time that maintaining even marginal existing capabilities is becoming increasingly difficult?
(2) How much institutional and social "invention" will be required and what will be the political costs?
(3) How much time will be needed before positive effects from institutional and technological "fixes" can overcome prospective weakening capacities to meet basic needs? This question is especially crucial given four characteristics of the current energy crisis in many developing countries: (a) the precipitous increase in imported oil prices has had a dramatic effect on domestic resources available for rural development programs; (b) the tendency for energy/GNP elasticities to reflect considerable energy inefficiency in early stages of industrialization, a factor that does not bode well for meeting the commercial energy requirements of rural areas given limited fuels and high costs; (c) the new energy requirements represented by continued rapid urbanization; and (d)

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the growing pressure on agriculture to provide liquid fuels for industrial and transport needs.

The discussions of paths to ecotopia are replete with technological and social fixes which tend to oversimplify both problems and solutions. It would seem clear, however, that the paths will vary widely with different sets of assessment issues involved.

Use of terms such as resilience, sustainability, or carrying capacity does not, by itself, introduce new social content into rural development analyses. It does introduce what are probably very important questions, but we would contend that sociology is not without some heritage of addressing such questions. Processes of integration and adaptation are key elements of theoretical and empirical work on social change. Proponents of ecological energetics and related models would argue that the ecological metaphor provides the broadest and most consistent calculus for translating energy into social content—the organization of the ecosystem. The problem is that the calculus operates by doing the reverse: it defines the organization of the ecosystem, including social systems, in energy terms (Axinn and Axinn, 1979). It is only from this perspective that the subsequent application of physical and biological principles to explain social change is logical.

If ecological frameworks are to be the dominant candidates for sociological analysis of energy and rural development, then two cautions should be raised:

(1) Sociologists should not assume that the meaning of energy is inaccessible or irrelevant. That is precisely the starting point for socially trivial insights or excessive compromise with energy reductionism.
(2) Biological metaphors cannot be transferred to the social sciences completely free of teleological brands of functionalism and confusion between irreversibilities in a physical system (ecodisaster) and loss of capability to maintain direction or absorb change (social disorganization).

Recommendations and conclusions

Our review was not meant to be a preamble to the selection of a "best" framework or the invention of any new frameworks. Our purpose, restated, is much more modest: to encourage more careful discussion of conceptions of energy and the sociological significance of energy. More careful discussion need not inevitably lead to the conclusion that a crisis in problem formulation is present. We are not suggesting there are such crises. What we are suggesting is that there are enough uncertainties to justify extra caution in using any of the frameworks to support categorical conclusions or policy recommendations.

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Does this amount to a pessimistic appraisal of rural sociology's potential contribution to understanding energy-rural development issues? Not at all. If we conclude that no one of the frameworks reviewed is totally adequate for rural energy research, we should also note that no single sociological framework is best for all non-energy problems or issues to which it might be applied. Sociologists, however, are not without conceptual and methodological tools to define and explore the problem of energy and rural development. It is only necessary to be especially judicious in choosing among these tools.

Regardless of which framework is employed, there is particular need for more careful statements about what is "unique" and what is most crucial in sociological terms about rural energy questions. Our perception of that need follows from the review of the frameworks, our association with a major eight-country energy and rural development research program (RSI, 1980), and extensive contact with rural energy research efforts internationally. Most rural sociologists are likely to be involved with relatively brief research enterprises that have relatively narrow objectives. Whether or not research proceeds under terms of reference basically defined by others, there are at least three issues which should be addressed as part of clarifying what is significant sociologically about energy in rural areas:

(1) *There is a need to maintain rigorous focus on likely patterns of access to decentralized energy technologies and on likely patterns of benefit from the utilization of such technologies.* What variabilities in different aspects of cropping system management are dampened or magnified by variabilities in access to energy resources? How are the food, fuel and income earning uses of basic food crops changed by altered access to firewood and commercial fossil fuels? How are such alterations reflected in patterns of agricultural diversification, especially in plant-animal and agroforestry based farming systems? What are the effects of alternate energy systems and fuel mixes on key household divisions of labor? On the overall quality-of-life characteristics of households and communities?

(2) *There is a need to specify under what social assumptions decentralized energy alternatives will be sustainable and what probable changes in the social environment could alter or enhance those assumptions.* How are occupational diversification and patterns of enterprise formation and expansion related to the organization and management of rural fuel systems? How do rural market centers affect access to renewable and non-renewable energy resources? How do variations in population density influence the management of common property resources like fuelwood? How do patterns of migration, seasonal labor movement and occupational mobility affect access to and use of alternate energy resources?

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(3) *There is a need to identify clearer criteria for determining success or failure of rural energy projects.* This is an issue that touches directly on competing uses for limited rural resources. Arguments for cassava-based energy farming on tropical upland soils, for example, must engage trade-offs between short-run cassava productivity and longer-run soil productivity. Fuller use of crop residues as biofuels may come at the cost of erosion damage, reduced soil fertility, undermined animal husbandry, or weakened in-kind payment mechanisms for farm labor.

We all have the responsibility to ask: When we extend our major analytical frameworks to rural energy issues, is our vision in or out of focus? This paper has suggested that at this early stage of research we should be careful in determining what it is we should be focusing on.

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Towards a Participatory Strategy for Integrated Rural Development

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ABSTRACT This paper outlines a strategy for achieving rural development goals and objectives through participatory research and systematic project development. The authors begin by detailing the essential elements required for any rural development program and propose their own definition of rural development. The paper then describes a seven-stage project development strategy which has proved successful in water management projects in Pakistan and Egypt. The paper delineates the key concepts in each of the seven stages and urges rural development practitioners to integrate more fully the client system into any rural development program.

Introduction

According to Julius Nyerere:

> Rural development is participation of people in a mutual learning experience involving themselves, their local resources, external change agents, and outside resources. People cannot be developed; they can develop themselves by participation in decisions and cooperative activities which affect their well-being. People are not being developed when they are herded like animals into new ventures (Boesen, 1977).

Some years ago, the *Far Eastern Economic Review* (1973) outlined some of the unique problems of the developing world. The journal called the developing world's predicament a man-made crisis and coined the acronym FAMINE: *failure* to develop adequate rural development policies and programs; *arrogance* of the urban and landed elites who perceive broad-based rural development as a threat; *mismanagement* of physical, economic, and human resources as well as wide spread official corruption; *internal disorder* resulting from non-representative government which does not reach and serve rural areas; *national isolation* due to the inability or lack of commitment to involve all classes of people in the development process; and *empty election pledges* by those who use rather than serve rural people. The FAMINE present in the developing world inspires and sets the stage for this paper which examines the current emphasis on essential rural development components and a participatory research-development strategy for integrated rural development programs.

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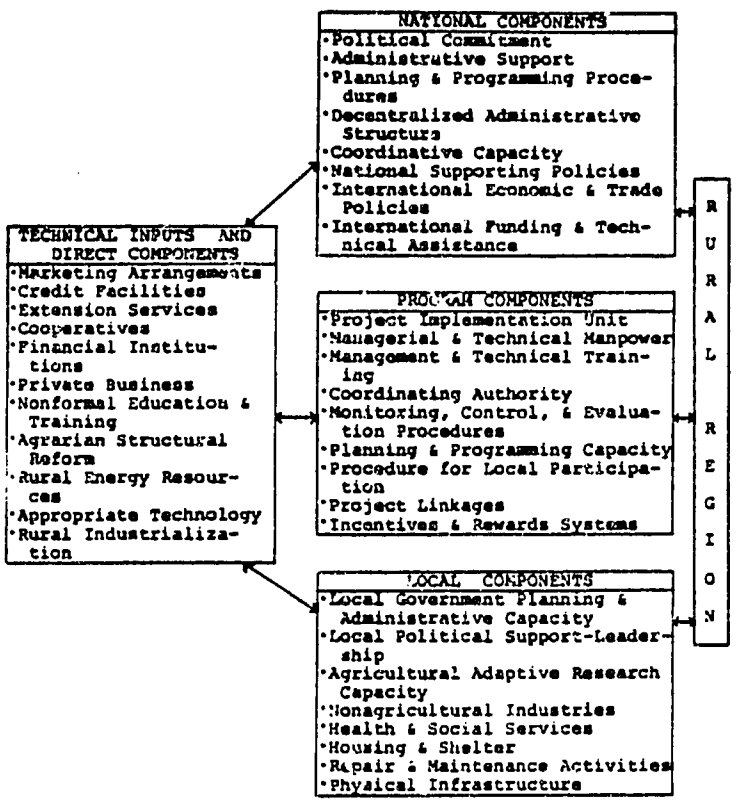

(Adapted from Rondinelli and Ruddle, 1978)

Figure 1. Functional components of integrated rural development

Present emphasis on essential rural development components

Due to discipline biases, lack of knowledge and the complex interdisciplinary nature of the subject, no general consensus exists regarding which combination of resources would best stimulate rapid rural development. The literature, however, points the way to four major categories of essential rural development strategy components. These include: (1) national policy and administrative inputs, (2) technical inputs, (3) local support components, and (4) programmatic inputs for project organizations and implementation (Rondinelli and Ruddle, 1978).

Figure 1 provides a listing of the detailed inputs needed for plan-

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ning and implementing rural development. A major problem for most experts in developing such detailed lists is that these inputs are exactly those in short supply in most LDCs (less-developed countries). Seldom does an expert provide ways and means of creating these essential inputs for rural development. In fact, if these inputs already existed in a LDC, that country would not be facing serious poverty and underutilization of physical and human resources! Development now requires a framework which will give us the means to evolve these essential components.

Rondinelli and Ruddle (1978) start us on the right track by synthesizing a number of major principles which appear to be essential for long-term integrated rural development. These principles include using existing resources and practices while carefully displacing unproductive and rigid traditional institutions; adopting modern technologies to local conditions and utilizing appropriate low-cost, culturally acceptable modes of planned change; designing a flexible process which will generate a sequence of strategic interventions; and actively involving the people to be affected by rural development.

While the list provided by Rondinelli and Ruddle (1978) is fairly extensive, they do not include other essentials, such as: establishing delivery systems for inputs and services to small producers; creating jobs; developing reasonable cost/benefit ratios to make the program profitable over time; stating objectives in socioeconomic terms; basing programs on area development and regional development plans; tying the programs into local industry; and emphasizing the production package concept, as well as quality of life activities (Fischer, 1975).

In this paper, we do not view rural development as a product or a result of increased rural income, employment, or education; we do not view it as an activity which divorces the rural sector from the urban sector; we do not view it as only a phase in general economic development. Instead, we look at rural development as a *process* involving both the rural and urban sectors in complementary activities. In the rural development process, intentional changes in the social structure drive institutions and organizations to produce desired changes in attitudes, behaviors, and skills (Capener and Brown, 1971).

Any attempted definition of rural development can be criticized due to the lack of theory and knowledge concerning the comprehensive nature of development. The ability to measure results accurately and the lack of objective priorities also make the definition process difficult. We believe, however, that a definition of rural development should include an emphasis on good management, a set of planned activities to attain goals, a clear focus on people involved, an indication of level of change to be attained, and a suggested set of proce-

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dures to create the desired change (Capener and Brown, 1971). Considering these criteria and over 24 years of collective experience in grass roots rural development programs, we have developed what we feel is a working definition of rural development. This evolving definition is stated as:

> *Rural development is a continuous process of planned social, political, and economic change in rural and urban social structures and organizations which provides for adequate incentives, production possibilities, and services to help rural people achieve higher levels of living, knowledge, and skills. Rural development helps to modify their physical and social environments and maintain sustained progress toward desired goals which the rural poor help establish and implement over time.*

In this definition special stress is given to self-help activities and to an acceptable level of local autonomy. We agree with Castle (1977) that:

> . . . Local autonomy is the very heart of rural development . . . Unless the rural community can, in some sense, exercise such autonomy in influencing its own destiny, it is better to let the rural community suffer 'benign neglect' than raise false expectations (Castle, 1977).

A critical caveat, however, must be mentioned. No rural community or rural development program based exclusively on self-help activities and isolated from the urban sector or the total economy can expect much success, whatever the rural humanists claim. Ties to the macro level must not be neglected, for they provide the resources for improved living and production possibilities. Lessons learned from China, Korea, Taiwan, Sri Lanka, and Tanzania demonstrate that while decentralization and increased local autonomy are important, a need exists for strong national commitment and intervention.

In order to implement programs based on the definition above, one must consider several basic ingredients (Council for Agricultural Science and Technology, 1974). Rural development requires an adequate *knowledge base*, built on empirical data, which can often contradict conventional wisdom and assumptions. Effective programs call for a consensus on a *policy base*, which allows rural development to be an integral, rather than a marginal, component of the social system. A self-sustaining *economic base* which increases the productivity of rural areas must be grounded in *local initiative* and *leadership development*.

Using these basic concepts, effective programs will require realistic time-frames and careful planning to achieve specific rather than general goals. Adequate funding will be required, as well as a focus on geographical areas of major need and opportunities. Finally, realistic

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methods of continuous monitoring and evaluation are required (Council for Agricultural Science and Technology, 1974).

A participatory research-development strategy for accelerated rural development programs

Background

The participatory research development strategy (PRDS) evolved from field experiences by a Colorado State University (CSU) team working in Pakistan on a local irrigation research-development program. In 1974, a sociologist and an irrigation engineer decided to study closely the actual process involved in researching, implementing and evaluating this development project. After a substantial period of conventional research, during which each disciplinary researcher worked in virtual isolation, they found that no one discipline could adequately understand or describe the dynamics of the on-farm irrigation system under study. The farmer client was generally ignored, while data were gathered independently by each discipline member, taken to an urban office, and reported with the usual recommendations. When development workers tried to implement programs at the farm level, farmers showed little enthusiasm and rejected these outside plans.

At this point, the CSU team members began a long and sometimes painful process of examining their assumptions and their methods, and concluded that they themselves were the major constraint to development, not the farmer-clients. Gradually a systems approach evolved which viewed the farmer and his family as the primary building blocks in rural development. Over time, with a systematic interdisciplinary team approach to a systems problem of water management, farmer clients began to respond enthusiastically to the program. Their cooperation increased and they began to participate in the design, implementation, and evaluation of their programs, based on their needs.

The United States Agency for International Development (USAID) requested the CSU/Pakistan On-Farm Water Management Project personnel to document their process. The results were published in several handbooks and transferred to other projects in Pakistan and elsewhere. (For more detailed description of the PRDS, see Clyma *et al.*, 1977.) To date, seven field manuals have been developed on several phases of the process; three intensive summer field training programs for Egyptians have been held; a two-volume training manual of field procedures has been written; three graduate courses have been team taught on the process at Colorado State University; and literally hundreds of researchers and technicians in Pakistan and Egypt have already been trained in the use of the PRDS. Several hundred million dollars are now invested in projects and programs

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for improving farming systems in Pakistan. These projects are supervised by a number of organizations, including USAID, the World Bank, and the Canadian Development Organization. In 1975–1976, CSU became involved in a similar project in Egypt and the process is now being field tested there in an irrigation farming system improvement project. Today USAID, FAO, the World Bank, and other international organizations are advocating this approach in other LDCs. This paper, however, is the first attempt to apply the process to overall rural development. We feel it is likely that the process can also be adapted to rural development programs in the developed countries.

Overview of the participatory research-development process

The process and its major components, with several overlapping and interrelated phases, is presented in Table 1. The process includes *preliminary reconnaissance* of the situation which provides the inputs to more intensive studies *identifying priority problems*. Once the priority problems have been adequately analyzed, research identifies viable *solutions*. The alternative solutions, thus identified, are then *assessed* in terms of technical, economic, social, and environmental impacts, and their organizational and political feasibility is studied. After these studies, recommended alternative solutions are made available for *project implementation*. Finally, formal evaluations of the project's impacts on target audiences are conducted and the project is then *reconsidered* for continuation, termination, or transfer to routine administration. The actual field methods for each phase are detailed in several reports and field manuals (Clyma *et al.*, 1977; Lowdermilk, 1981a, 1981b).

Some general guidelines for using the PRDS approach follow. First, we do not advocate a "lock step" approach because in the real world the practitioner will be involved in an iterative process.

Second, the eight key concepts described are vital in each phase of the PRDS. Though some are more important than others in particular phases, all key concepts are integral to the entire process.

Third, at each stage the project team must state clear objectives and front-load all their implicit and explicit assumptions. Failure to consider realistic objectives will result in shoddy design and useless efforts. We recognize that objective setting is a frustrating experience for many individuals. Rural development, however, is no place for the perfectionists, planners, and intellectual academics who expect success to flow from merely recommending more and more research and planning (Rondinelli and Ruddle, 1978). At best, rural development in all its complexities is a tough operation. It can, however, be made less messy and much more effective by stating clear, precise objectives and by using a systematic approach. The seven phases that make up this approach are outlined below.

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Table 1. Phases and major characteristics of a participatory strategy for rural development

Key concepts and major emphases for all phases	
(1) Systems approach	(5) Valuation
(2) Interdisciplinary team work	(6) Training focus
(3) Client involvement	(7) Institutional linkages
(4) Learning process	(8) Monitoring/evaluation

Phased sequences	Major emphases	Major activities
Phase I		
Preliminary reconnaissance	Systems approach; interdisciplinary teamwork; preliminary objectives; overview of system; policy commitment	Review existing data; key informant interviews; mini-surveys; check lists; field visits; selection of sites
Phase II		
Priority problem identification studies	Learning process; training; clinical approach; understanding of systems	Delineation of system; formal field studies; quantitative and qualitative system description; prioritize constraints
Phase III		
Search for solutions	Client involvement; applied, adaptive, and evaluative socio-technical research under rural conditions; trial and adoption	Experiments, trial, and demonstrations; packaging of innovations
Phase IV		
Assessment of solutions	Valuation; client acceptance; transfer vehicles; micro-macro diffusion requirements	Adoption-diffusion studies; communication systems evaluation; select alternative packages
Phase V		
Project implementation	Institutional linkages; client oriented; integrated planning; management; client participation	planning; design; implementation; monitoring; institution building
Phase VI		
Formal project evaluation	Monitoring; technical, social, economic, environmental, organizational focus	Diagnosis of failures and successes; formulation of recommendations
Phase VII		
Project reconsideration or completion	Project continuation; return to normal administration; completion or termination	Policy decisions

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Phase I: preliminary reconnaissance. The purpose of this phase is to gain information about the rural social system in question so that the planning for Phase II will be as unbiased as possible. Reconnaissance is a team learning experience and includes a review and synthesis of existing knowledge and data. Following specific checklists, information is gathered from "quick and clean" mini-surveys, interviews, and field visits, and then synthesized into usable form. Researchers gain knowledge from officials, clients, and auxiliary personnel.

In this preliminary reconnaissance phase and throughout the process, a systems approach to rural development is an absolute necessity. A rural community is an open system related to the economic and political system of a nation. Likewise, a rural community is an adaptive system which changes in relationship to both internal and external influences (Chin, 1976). A rural community is also a man-made system to achieve certain human goals. Rural development, therefore, is not an isolated process, but affects and is affected by population, environment, technology, and organizations (Duncan, 1959).

Given a systems approach, with its different components, relevant disciplines for project personnel need to be identified. No single discipline has an edge on rural development. An interdisciplinary team approach is needed at each phase. The general principle is to gather the necessary disciplines around a given problem area rather than indiscriminantly forming teams and automatically including pre-determined disciplines. Without team members who have expertise, maturity, experience, and respect for each discipline's contribution, the process will not work effectively.

Phase II: priority problem identification field studies. From the information gathered during the preliminary reconnaissance, the team designs specific detailed studies to identify priority problems. These problems or constraints prevent the social system from achieving its realistic goals. Phase II generates both quantitative and qualitative data and provides benchmark data for future evaluations. Furthermore, it presents a good opportunity for training technicians, extension workers, and clients in problem identification and analysis.

This training focus is another key concept in the PRDS and includes training change agents and clients alike. The initial cadre of workers who acquire skills in the early phases of the PRDS provide good candidates for trainers needed in the more policy-oriented later phases of the process. Their use can overcome the conventional approach of task specialization. Certainly specialization is needed in developed countries where sophisticated technologies demand highly trained manpower. In most LDCs, however, there are few well-trained individuals who have lived for long periods in rural areas and adequately understand the rural system. Therefore, at least initially, a cadre of technical personnel should be trained in the total PRDS.

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During the training process, two-way learning also takes place. Through joint collaboration and open two-way information flows, both clients and change agents learn step-by-step, often by non-formal educational processes which do not demand literacy as a prerequisite (Coombs and Ahmed, 1974). The PRDS learning model links the valuable expertise of the change agent to the local wisdom of clients. Through collaborative efforts and even trial and error, practitioners and farmers are involved in growth or development. When continuous learning takes place, adequate development usually accompanies it (Kulp, 1977).

Phase III: search for solutions. Phase III takes the priority problems identified in Phase II and develops solutions through participatory research methods. Since organized problem-solving is still an inexact science, the development of systematic solutions is often problematic. Figure 2, however, shows a flow chart of a possible process. The solutions evolved in the rural community provide the input for Phase IV where a complete assessment takes place.

In the search for solutions phase, client participation is absolutely essential. Though farmer participation in project activities is not a new concept, it is only in the past few years that it has enjoyed a true resurgence. Recent research and development literature has studied new ways and means to structure client involvement. In several novel projects, participatory research methods consider the farmer-clients as vital components in all project phases rather than merely passive bystanders or information sources to be mined. Additionally, the disruptive influences of factions and social class groupings can be minimized by developing and nurturing leadership opportunities for the entire client system. Extension oriented research, for instance, has always considered it essential for clients to take part in assessment of resources, identification of problems, search for alternative solutions, implementation of programs and evaluation of results.

The fear that client participation will waste time, contaminate data and bias results has no place in action-oriented research for rural development. If learning and local initiative are important, programs must be tailored to local conditions. Outside planners simply cannot anticipate or evaluate adequately without the participation of the people directly involved. Indeed, a recent field study of 36 rural development projects in Africa and Latin America found that 49 percent of the variation in overall project success was explained by client involvement and resource commitment (Development Alternatives, Inc., 1975).

Experience suggests that coercion, lecturing, or manipulation do not create sustained progress in rural areas. A cadre of highly trained and motivated development workers can help to ensure that voluntary participation is an on-going, continuous process. If client involvement is not ultimately self-sustaining, then it is not true development

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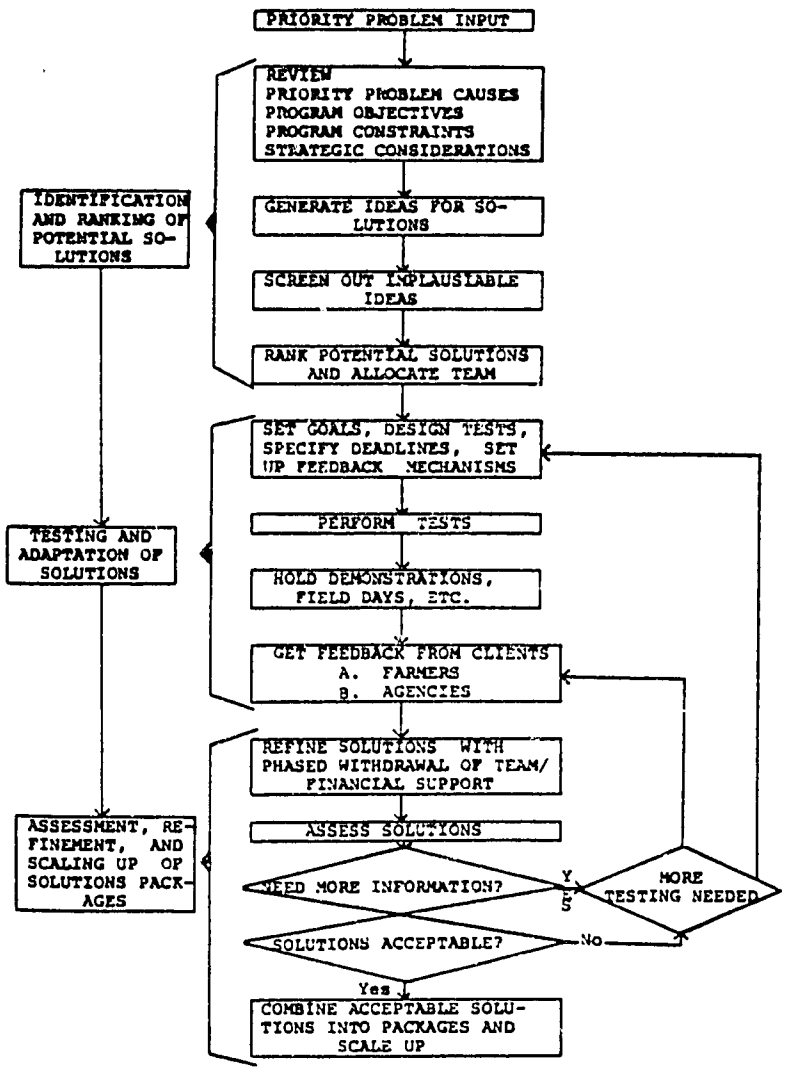

Figure 2. Systematic framework for development of solutions.

(Fischer, 1975). Long-term rural development is possible only where client participation is encouraged, not coerced.

Phase IV: assessment of solutions. The assessment of solutions phase tests the socioeconomic packages derived in Phase III. Here we need to ascertain the usefulness of the solutions, as well as their feasibility,

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and organization requirement. We recognize that all solutions cannot be fully tested before implementation. Policy changes, for instance, can only be estimated after the fact by ex post methods. Nevertheless, recommendations can be made about the policy changes required to meet certain goals. This aspect of the assessment of solutions phase, therefore, requires policy analysis training for the rural development researcher, scholar, and practitioner. The output of Phase IV is a set of alternative packages with feasibility analyses available for policy makers.

Phase IV concerns itself in particular with an often neglected component of rural development: valuation. As a concept, valuation is the process of analyzing value criteria and of making assumptions explicit rather than implicit. Each objective must be analyzed in terms of compatibility. Otherwise, objectives could easily conflict with one another. Researchers and policy makers must consider value criteria such as improved agricultural production, increased employment, and more equitable income distribution in order to test each technology recommended. Those criteria in turn, are evaluated in terms of whether they lead to these objectives or increase negative externalities in some target group. At each phase of the PRDS, therefore, clear objectives with consistent assumptions are placed "up front" and used both as guides and tests to examine each phase's activities.

Phase V: project implementation. At this point in the PRDS, the research output enters a political and planning arena. The purpose of this phase is to gain official approval for a project or program. Planners submit the definition and description of the proposed project, develop feasibility assessments from the macro perspective, and construct the project's organizational design. A strong need exists for technical personnel who know how to design projects, communicate with planners, and negotiate with officials. The need for such personnel is particularly acute when fierce competition arises between government agencies for control of projects. This rivalry between agencies can delay or even abort project implementation.

Some basic questions need to be asked in the project's description and definition. What are the likely economic, social, and political consequences if the project is not implemented? What are the criteria for giving priority to this particular project? How does this project fit into both short and long-run development strategy? What are the linkages with existing micro and macro institutions? These questions represent only a small sample of the hundreds of questions which project designers must raise and answer to satisfy government ministries and funding agencies.

The development of institutional linkages is particularly important during the project implementation phase. No rural community exists in isolation, whatever the rural romantics of the folk culture school claim (see Popkin, 1979). To ensure long-term success, rural devel-

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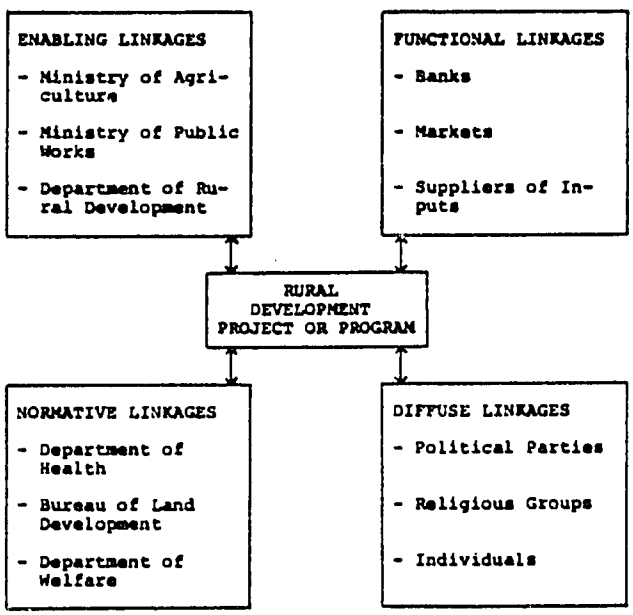

Figure 3. Rural development projects and institutional linkages.

opment projects must develop systematic linkages with urban development and the total economy.

Figure 3 provides a simple mapping procedure for four major types of organizational linkages. Project personnel should intentionally develop and maintain these linkages in each phase of the PRDS. Enabling linkages tie the project to organizations which provide authority, funds, and bureaucratic resources. Functional linkages supply physical inputs and services, and also utilize the outputs of agricultural or small industrial projects. Normative linkages connect the project to organizations sharing the same goals, values, or norms. Diffuse linkages provide allies and supporters for the program.

A successful rural development program must identify and nurture these necessary linkages. Rural development practitioners should remember that any organizational innovation initially exists in a turbulent environment. It needs to be secured by good linkages with supporting organizations. As a number of observers have pointed out, few scholars, researchers, and practitioners have acquainted themselves with the extensive body of knowledge concerning strategies for institution building (Blase, 1973; CIC-AID, 1968; Mann, 1975; Thomas *et al.*, 1972; Utah State University-AID, 1970).

Phase VI: formal project evaluation. Formal periodic evaluation, usually

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by persons external to the project, is not in conflict with continuous internal evaluation and monitoring. The evaluation should provide a learning experience about the project's strengths and weaknesses. These experiences should help in the design and implementation of other projects. Perhaps one of the weakest links in the rural development process occurs at this evaluation phase (Waterson, 1976). A good evaluation is not only a project survival technique, but a valuable tool for future project design. The main purpose, then, is not to conduct an audit, but to help the project personnel improve the project's impact on the client system.

We should stress that project evaluation is important in each phase of the PRDS. The monitoring of staff, research activities, development of solutions, assessment of technologies, project implementation, and training must be continuous in order to maintain performance standards and provide feedback for correcting procedures and improving activities. Without monitoring and good supervision, projects will inevitably fail to meet objectives. The absence of a "memory" in most rural development projects is a common weakness. To improve memory and make the PRDS a learning process, timely internal evaluations are important for both project personnel and sponsors.

A sad reality is that we know so little about rural development. Part of this lack of knowledge is directly attributable to the lack of good evaluation data and the propensity to think of only case-by-case evaluations rather than a cross-project or cross-country cooperative evaluation. The PRDS hopes to correct these data deficiencies.

Phase VII: project completion. This final phase utilizes data from the formal evaluations and decides future courses of action. Both planners and implementors seldom plan for project completion or termination. *When* and *how* the project will be turned over to routine administration is rarely considered. A project is successful when it is institutionalized and able to continue on a sustained basis with scaled down project personnel. Few personnel think of the possibility of project completion or termination, but good reasons exist for building the necessary termination procedures into the project design. Phasing down for transfer to a routine organization is crucial. When such plans are not made in advance, the decision may be abrupt and thus place the total operation in jeopardy.

Since any project by nature is limited by space and time, it should not continue indefinitely. Advance planning can ensure the smooth institutionalization of project activities into a routine organization. Project planners should also develop criteria for project termination short of the target date. Such criteria should include failure to benefit intended clients, spread effects too limited, inappropriate use of project outputs by clients, failure of agencies to train local people, and/or corruption.

Conclusion

Over a decade ago, Wharton (1969) raised the question, "cornucopia or Pandora's Box?" regarding the Green Revolution's programs. We raise the same question in the context of rural development. Pandora's Box may be the lack of focus on broad-based rural development which produces poverty and hunger as its vociferous stepchildren. We feel that the tragic situation encapsulated by the FAMINE acronym can be reversed by adopting the PRDS and similar strategies. As an alternative acronym, we propose ABUNDANCE: *agricultural* production possibilities to *better utilize* physical and human resources; *non-interference* of urban elites in the rural development programs for the poor; *doubling of efforts* in systematic basic human needs programs; *avenues* for rural people to participate in policy and program decisions which affect their livelihoods; *non-involvement* of religious leaders in the policies of many countries; *crisis management* of rural development programs replaced by effective management; and finally, *enlargement* of farmers' options to play a larger role in food production. From prior experience, we believe that the PRDS can contribute to improved rural development by closing Pandora's Box and providing rural people a little more cornucopia.

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Melvin E. Walker, Jr.,
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AN INTEGRATED APPROACH TO RURAL DEVELOPMENT

Melvin E. Walker, Jr.

Toward an Integrated Approach to Rural Development

Having so defined development, the immediate task becomes that of discerning the following: (1) what is involved in the process of rural development, (2) whose collective efforts are necessary for effective development, and (3) how the process will be evaluated, that is, what mechanisms will be used to assess the degree to which the goal of improved quality of life has been achieved?

Rural development involves several processes; the most essential process is that of helping rural people help themselves--helping them identify their problems and needs and then aiding them in the acquisition and mobilization of resources necessary for alleviating or satisfying these problems and needs. Too often, "experts" who are outsiders look at an area and decide what is needed, such as new industries for employment or increased mechanization of farms for efficiency, only to discover later that these prescribed "remedies" have created a greater number of more serious problems such as higher taxes for the same rural residents who remain unemployed and higher financial liabilities for farmers as they attempt to adjust to resulting change. Helping rural people help themselves means involving those affected in identifying

and planning for activities which may result in changes in the economic, social, physical and environmental conditions in their lives and communities.

The approach to rural development adopted here does not necessitate reference to specific change projects addressing the potential for industrial development, better educational, medical and recreational facilities or projects focusing on making small farms more efficient, although projects such as these are important means to accomplishing the desired goal of improved quality of life. Instead, attention is focused on facilitating the organization and problem-solving capacity of rural communities at the appropriate level be it local, state, regional or national. This problem-solving capacity is then directed toward bringing about positive change at at least three (3) levels: (1) individual maintenance--helping individuals and families meet current needs for basic nceessities such as food, clothing, and shelter--, (2) individual capacity--helping individuals and families improve their long-term ability to sustain themselves through the provision of education, health care, mental health programs, family counseling, etc., and (3) community service programming--providing new or extended programs or services to groups of individuals and families with maintenance and capacity needs rather than directing help to individuals or individual families (Nix, 1977).

Efforts to bring about changes at these levels will, in turn, result in specific problem-solving activities or projects, if you will, in the following areas: (1) human development, (2) economic development, (3) environmental enhancement or preservation, and (4) improvements in public facilities (Carlson et al., 1981). But again, the delineation of

Table 1

ANNUAL PER CAPITA GRAIN AND CROPLAND REQUIREMENTS FOR FOOD AND FOR AUTOMOTIVE FUEL

	Grain	Cropland*
	(pounds)	*(acres)*
Subsistence Diet	400	.2
Affluent Diet	1,600	.9
Typical European Automobile** (7,000 miles/yr. at 25 mpg)	6,200	3.3
Typical U.S. Automobile** (10,000 miles/yr. at 15 mpg)	14,600	7.8

*Based on average world grain yields in 1978, according to the U.S. Department of Agriculture.

**Fuel use converted at 380 liters of alcohol per metric ton of grain.

SOURCE: Worldwatch Institute.

ever, growth in world food output has slowed, scarcely keeping pace with population growth. The failure of world grain output to match the increase in both population and incomes led to rising food prices during the seventies.[24]

Population and Supply

World demand for grain has been expanding by some 30 million tons per year over the past decade. Of this total, the bulk is needed to feed the increased number of humans, leaving little to upgrade diets. While world population growth has slowed, the absolute year-to-year increase remains at 70 million. In effect, the gradual decline in the rate of population growth has been offset by the increase in the size of the population base.[25]

Although population growth has dominated the growth in world food demand, rising incomes have also contributed to the increase, particularly in areas where consumption of livestock products, and the grain to produce them, has been rising rapidly. Prominent among these are a few industrial countries, such as Japan and the USSR, where meat consumption has until recently been relatively low, and the oil-exporting countries, where incomes are rising at an unprecedented rate.

On the supply side, growth in the world cropland base has slowed markedly since mid-century, expanding only one-fifth as fast as population. Other prominent reasons for the slowing growth in world food output are the continuing conversion of prime cropland to nonfarm uses, the excessive erosion of soil on at least one-fifth of the world's cropland base, the rising cost of energy for farmers, and the diminishing returns on additional applications of fertilizer in agriculturally advanced countries.[26]

All the forces that contributed to the loss of momentum on the food front during the seventies seem certain to intensify in the eighties. Even without the competition from energy crops, the world will be hard pressed to avoid a decline in per capita food production during the decade if the projected increases in population materialize. It is against this backdrop that the emergence of national energy crops initiatives must be evaluated.

Food versus Fuel

The potential claim of automobiles on future food-producing resources can best be illustrated by comparing the area of cropland required to feed a person with that needed to run an automobile on ethanol. Per capita grain consumption in developing countries averages roughly 400 pounds annually, or just over a pound per day. In the most affluent countries, where diets are rich in livestock products, each person annually consumes an average of 1,600 pounds of grain, including the amount eaten directly in cereal products and that consumed indirectly in the form of meat, milk, and eggs.[27] At average yields of grain, satisfying the annual food needs of a typical consumer in the Third World requires roughly one-quarter of an acre of cropland, whereas the more affluent consumer requires nearly an acre. (See Table 1.)

An automobile run on ethanol requires far more grain than a person does. A typical American car fueled by ethanol would require the processing of over seven tons of grain per year. In Western Europe, where cars are more fuel-efficient and are driven less, the typical automobile could be run on a little over three tons of grain per year. These numbers are in a sense hypothetical because, except for Brazil, no country has yet proposed running automobiles exclusively on alcohol. As for gasohol, fueling the typical U.S. car would require 1,460 pounds of grain in order to provide a 10 percent mix of ethanol with gasoline.

The social and political ramifications of a massive production of energy crops will probably surface first in Brazil, the only country that is committed to running its entire fleet of cars on alcohol. When President Figueiredo signed a protocol in September 1979 with the National Automakers Association confirming the intention of producing 250,000 automobiles in 1980 that would run entirely on alcohol, he was in effect claiming some 200,000 hectares of cropland for sugarcane. Government plans to produce 10.7 billion liters of alcohol by 1985 will require nearly three million hectares of sugarcane, the equivalent of 10 percent of Brazil's cropland. If the far more bullish projections of the alcohol fuel industry materialize, production will reach 20 billion liters and the area planted to sugarcane for fuel will approach one-fifth of the country's cropland.[28]

Brazil has one of the world's most widely skewed income distribution patterns, with a ratio of 36 to 1 between the average income of the richest one-fifth of its population and that of the poorest one-fifth. Evidence of malnutrition has been found in the country's high infant mortality rate and in the fact that less than half the children

Table 2

THE CHANGING PATTERN OF WORLD GRAIN TRADE*

Region	1934-38	1948-52	1960	1970	1978
		(million metric tons)			
North America	+ 5	+23	+39	+56	+104
Latin America	+ 9	+ 1	0	+ 4	0
Western Europe	−24	−22	−25	−30	− 21
Eastern Europe & USSR	+ 5	0	0	0	− 27
Africa	+ 1	0	− 2	− 5	− 12
Asia	+ 2	− 6	−17	−37	− 53
Australia & N. Zeal.	+ 3	+ 3	+ 6	+12	+ 14

*Plus sign indicates net exports; minus sign, net imports.

SOURCE: Food and Agriculture Organization, U.S. Department of Agriculture, and author's estimates.

under the age of 18 in 1975 had reached the normal weight for their age.[29]

The decision to turn to energy crops to fuel the country's rapidly growing fleet of automobiles is certain to drive food prices upward, thus leading to more severe malnutrition among the poor. In effect, the more affluent one-fifth of the population who own most of the automobiles will dramatically increase their individual claims on cropland from roughly one to at least three acres, further squeezing the millions who are at the low end of the Brazilian economic ladder.

Despite its vast land resources, Brazil is a chronically grain-deficit country, drawing on grain imported from abroad. Brazilian officials claim, however, that the production of energy crops will be in addition to rather than in competition with that of food crops. Yet energy crops compete not only for land but also for agricultural investment capital, water, fertilizer, farm management skills, farm-to-market roads, agricultural credit, and technical advisory services. In the absence of a planned economy where all agricultural inputs are carefully controlled and clearly tagged for the production of either food or energy, it would seem to be impossible to launch a major energy crops program without siphoning resources away from food production. The assumption that energy crops will not compete with food crops may be both naive and politically risky. The upward pressure on food prices that will be generated by the rapid expansion of energy crop production could put a severe strain on the Brazilian social fabric and political system.

The immediate consequences of the Brazilian energy crops program may be more internal than external, but the more recently launched effort in the United States has broader ramifications. If U.S. cropland is shifted to energy crops to fuel automobiles on a massive scale, it will be at the expense of our exportable surplus of grain. Over the past generation, the entire world has come to depend heavily on North American grain exports, with just over four-fifths of the total coming from the United States. (See Table 2.)

All but a handful of countries now import grain, most of it from North America. Since World War II, scores of countries have become food importers; yet not one new country has emerged as a significant cereal exporter during this period. Close to a dozen countries —including Algeria, Belgium, Japan, Lebanon, Libya, Senegal, Singapore, Switzerland, and Venezuela—now import more than half their total grain supplies.[30]

The cereals exported from North America—enough to feed 500 million people at Third World consumption levels—consist of large quantities of both food and feed grains, principally wheat and corn. And as more and more alcohol fuel distilleries are built in the United States in order to meet the official goal of producing two billion gallons of ethanol by the mid-eighties, the exportable surplus of grain will be reduced accordingly.

Making the Choice

Turning to energy crops as a source of automotive fuel opens a new chapter in the history of human efforts to achieve an adequate food supply. For the first time since agriculture began, the world is faced with a potentially massive diversion of agricultural resources to the production of nonfood crops. Unfortunately, this is beginning to happen at a time when efforts to expand world food output are losing momentum, when food prices are rising, and when malnutrition is increasing.

Whether the use of cropland to produce fuel for automobiles can be justified is a complex issue, one that political leaders will be wrestling with for years to come. Of the many considerations, the most critical one may be the difference between the perceived national interest in energy crops of food-surplus countries and that of food-deficit countries.

The attractions of alcohol fuel are clear. For countries buffeted by soaring oil prices and possible supply disruptions, the prospect of an easily available substitute for some of the imported oil is an inviting one. Although the world's oil reserves are concentrated in a handful of countries, the potential for producing energy crops is as widely diffused as agriculture itself.

There are also some solid environmental reasons to support alcohol fuel: it is clean-burning when used alone and when mixed with gasoline, it can substitute for lead as an octane booster. In contrast to the burning of petroleum, liquefied coal, or other automotive fuel of fossil origin, alcohol produced from plant materials does not increase the amount of carbon dioxide in the atmosphere, unless of course it leads to an overall reduction in the plant material in the world. In addition, alcohol is a renewable resource, a potentially important component in any effort to create a sustainable economy.

Economically, the move toward alcohol fuel is often justified by the additional employment it would create. Energy crop production and alcohol distillation are far more labor-intensive than are oil production and refining. And because distilleries are dispersed throughout the countryside, close to their feedstock supplies, they generate industrial as well as on-farm employment in rural areas where unemployment is usually highest. Jobs created in the countryside of the Third World can also help slow the migration to the mushrooming squatter settlements that surround so many cities.

The attractions of agriculturally derived alcohol fuel must be set against its potential impact on world food prices. By far the most serious environmental impact of energy crops will be the additional pressures they put on cropland. The doubling of world food output over the past generation has led to the adoption of cropping practices that are resulting in excessive soil erosion. At least one-fifth of the world's cropland is now losing topsoil at a rate that is undermining its productivity. With the demand for food projected to double again over the next generation, it will be difficult to lighten the demands on soils and to arrest their long-term deterioration. If, in addition, vast areas are planted to energy crops, the problem will become even more unmanageable.

As the number of distilleries multiplies, the production of energy crops will expand until an economic equilibrium is reached between the price of agricultural commodities used as distillery feedstock and those used for food or feed. In the absence of any governmental limitations on the conversion of agricultural commodities into fuel, the price of oil could eventually set the price of food.

The expanding production of fuel crops will underline the vast disparities in income within and among societies as perhaps nothing else has ever done. Until recently, the average per capita claim on the earth's food-producing resources has not usually varied from the richest to the poorest countries by more than a factor of five to one. With the advent of energy crops, however, the ratio could increase dramatically. In effect, the use of energy crops to fuel automobiles permits the world's affluent to expand greatly their claim on the world's cropland area.

The question is not whether there should be an alcohol fuel industry. Clearly, there are many possibilities for converting agricultural wastes and other sources of plant materials into automotive fuels that need to be urgently pursued. Over the longer term, a carefully designed alcohol fuel program based on forest products and cellulosic materials of agricultural origin could become an important source of fuel, one that would not compete with food production. Liquid fuel from plants, whether in the form of alcohol or as direct hydrocarbon extracts, is an energy source that needs to be aggressively exploited everywhere. At issue is whether governments can encourage the production of alcohol fuel without inadvertently launching an industry that competes directly with food production.

If the potentially adverse effects of

Gasohol, a 10 percent alcohol-with-gasoline mixture, has so far been introduced in only a few places in the United States.

Jane Scully

current programs to produce fuel from crops are to be minimized, several steps must be taken immediately. The governments launching these programs need to warn food-deficit countries of the potential reduction in exportable food surpluses so that they can adjust their agricultural and population policies accordingly. Secondly, the move toward energy crops reinforces the need for an internationally coordinated effort to arrest the excessive erosion of topsoil. Without such an initiative, the widespread planting of energy crops will accelerate the deterioration of the world's cropland base. Where agricultural fuel programs are launched, priority in the use of fuel should be given to tractors and other farm uses over automobiles. And finally, a global food-price monitoring system that would be sensitive to the impact of alcohol fuel programs is needed. Such a system is essential if political leaders are to assess the worldwide impact of national energy crops initiatives on food prices.

Within the food-exporting countries, the short-run attractions of converting exportable food surpluses into alcohol fuel are undeniable. Whether the longer term political effects will be as attractive is less clear. In a world that no longer has any excess food production capacity, the decision to channel foodstuffs into the production of automotive fuel will inevitably drive food prices upward. For the world's affluent, such rises in food prices may lead to belt-tightening; but for the several hundred million who are already spending most of their meager incomes on food, continually rising food prices will further narrow the thin margin of survival.

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THE Conversion OF Tropical Forests

BY NORMAN MYERS

THE TROPICAL MOIST FOREST BIOME (ecological community) is biologically the richest and least well-known portion of the earth's surface. In this biome are to be found several million kinds of organisms, of which no more than half a million have even been given a Latin name. Many of the known and unknown species of organisms in the tropics offer significant potential for utilization by man, and all are of intrinsic scientific interest. A number of tropical plants, including rubber and oil palm, have been brought into wide-scale cultivation within the past century. Many more should be investigated as to their useful properties.[1]

Not only is the tropical moist forest (TMF) biome large and spread across three tropical regions, but it is much more differentiated than many observers suppose.[2] It is divided among some 70 countries, of which almost 40 contain tracts of TMF that are appreciable in size or significant for their ecological and biotic values. However, more than four-fifths of the biome occurs in only nine countries—Bolivia, Brazil, Colombia, Peru, and Venezuela in Latin America; Indonesia and Malaysia in Southeast Asia; and Gabon and Zaire in Africa.

Biotic Diversity

The TMF biome is, biologically and ecologically, the most complex and diverse on earth. There is marked diversity of species, especially of trees, woody climbers, and epiphytes. This characteristic is most notable in wetter areas with high atmospheric humidity. The complexity is both dynamic (with an exceptional degree of biotic and physiobiotic interactions) and stable (able to maintain itself for long periods if not indefinitely).

It is a mistake to suppose, however, that this diversity and stability are interrelated in a simple and positive fashion. Indeed, recent theoretical and empirical research suggests that "communities with a rich array of species and complex web interactions (the tropical rainforest being the paradigm) are likely to be more fragile than relatively simple and robust temperate ecosystems."[3]

The dynamic relationship between complexity and stability is particularly significant since it appears to depend on an important provision,

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Fertilizing young oil palms in the main nursery before later replanting in cleared jungle in the Jengka Triangle in the State of Pahang, West Malaysia.

namely that external forces impinging on the system should not exceed certain threshold values; otherwise distinct and enduring changes may arise. Human intervention—which can be massive both in terms of immediate impact and long-run duration—can readily exceed the capacity of TMF regulatory processes to maintain the system.

TMF species are unusually susceptible to extinction because many have highly specialized ecological requirements, many exist at low densities, many are confined to localized distributions. These three attributes alone mean that these species are highly vulnerable to sudden elimination when a tract of forest is subjected to the more disruptive forms of conversion: a tract of forest does not have to be entirely cleared for a number of its resident species to become extinct.

Elimination of a substantial proportion of the planetary spectrum of species will mean a gross reduction of life's diversity on earth: it will entail a permanent shift in the course of evolution, and an irreversible loss of economic opportunity as well.

Primary and Secondary Forests

Primary forest is forest that has been undisturbed for a long time—at least for decades and sometimes for centuries. Primary forest often consists of forest that has worked its way through successional stages of development as a young forest and is now approaching or has attained a state of maturity, often considered to be a state of ultimate diversity and complexity. Such a formation has been termed by some researchers a climax forest—one representing a vegetation type in dynamic equilibrium with the climate in which it occurs.

The make-up of plant species in a secondary forest is fundamentally different from that in a primary forest. In addition, the structure and functioning of the community are different, and the ecosystem is less diverse. After a tropical primary forest has been cleared, and the plant life left to regrow, there is a rapid accumulation of new biomass until it peaks at roughly 15 years—after which only the nature of the plant life changes.[4] Through a process that occurs slowly, or extremely slowly, pioneer species and low-ground vegetation disappear, their detritus providing nutrients for larger and longer-lived trees. Eventually the secondary forest develops steadily toward a formation akin to that of primary forest; and in time, provided all the necessary complex of factors is available, primary forest will reestablish itself.

But secondary forests tend to persist for long periods. In areas of disturbed rainforest in northeastern Australia, 50 years' regeneration has produced forests that are floristically similar to nearby undisturbed forest but that are still structurally dissimilar.[5] Around Angkor in Kampuchea (Cambodia) the forest of large areas that were reputedly cleared 600 years ago does not yet fully resemble surrounding patches of undisturbed primary

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forest. Indeed, it is thought that certain lowland rainforest ecosystems after being grossly disrupted or destroyed may need a successional process of as much as 1,000 years before a final-form primary forest ecosystem is reestablished.[6] Although natural forces, such as typhoons, can also damage primary forests, generally speaking, it is human influence that causes secondary forests to appear in the contemporary TMF biome.

Causes of Conversion

By far the most important factor in conversion of tropical moist forests appears to be the forest farmer, whether using traditional shifting cultivation, smallholder agriculture, or some type of squatter colonization. It has been estimated that, in the mid-1970s, these forest farmers totaled at least 140 million, occupying some 2 million km^2 (or over one-fifth) of the TMF biome.[7]

There is reason to believe that the estimation of 140 million forest farmers represents a minimum number. At an average size of seven persons per family (a roughly acceptable figure for Central America, Colombia, Indonesia, the Philippines, and Thailand), this means there are some 20 million families. If each family clears one additional hectare each year, as seems to be minimal practice, the forest farmers are clearing some 200,000 km^2 of forest each year. Although many of these farmers exploit secondary forests and although in certain sectors of primary forest (for example, in Central Africa) population densities are still low enough to permit the forest to be used while sustaining its quality and composition with prospect of eventual regeneration of primary vegetation, it is not unrealistic to suppose that forest farmers are converting at least 100,000 km^2 of primary forest to permanent cultivation each year. Thus forest farming could well be accounting for the loss of over 1 percent of the TMF biome each year.

Cattle raising also plays a substantial role in the conversion of tropical moist forests, especially in Latin America. Between 1950 and 1975, the area of man-established pasture in Central America more than doubled, almost entirely at the expense of primary moist forests. In Brazilian Amazonia cattle raising is now the dominant cause of forest conversion. Although many cattle ranches in Amazonia become unprofitable within less than 10 years because the productivity of the newly created grasslands declines, a rancher can generally obtain another patch of forest to clear, thus practicing a new and broad-scale variation of shifting agriculture. As long as beef continues to bring high prices in the developed world, cattle raising is likely to be an increasingly important cause of destruction of primary TMF.

One of the main reasons for the growing exploitation of tropical moist forests is the desire for more wood. This is true not only of the tropical countries but of communities in the developed world that increasingly look to TMF to meet their consumption demands.[8] Although the tropical moist forests contain about as much wood as their temperate counterparts, TMF now supply little more than one-tenth of total wood used worldwide as solid wood and as paper pulp.

The Timber Trade

During the last three decades, there has been a rapidly growing demand on the part of developed nations for tropical timber, especially for hardwoods, the kind of timber that makes up over 90 percent of TMF (Table 1). Hardwood supplies many needs: housing construction; finished products such as furniture; and wood-based panels such as plywood, veneer, particleboard, and fiberboard. Of the world's hardwood forests, the great bulk are located in the tropics. Hardwood forests of temperate zones have been steadily depleted or are coming under greater protection in order to meet environmental interests and, as a result, exploitation pressure is increasingly directed toward TMF.

After the economies of the developed world recovered from World War II, they began to import tropical hardwood timber, some 4.2 million m^3 in 1950 (Table 1). Within three decades, the volume has grown by almost 1,500 percent, and it is projected to expand by more than half as much again, to 95,000,000 m^3 by the year 2000. True, tropical regions use a lot of hardwood timber themselves, but the amount has little more than doubled since 1950, whereas the developed world's imports have increased 15 times, and the total has recently surpassed consumption by all tropical countries combined.

The largest single consumer of tropical hardwoods is Japan, now accounting for over half of the developed nations' imports (Table 1). Between 1950 and 1973, Japan's consumption of tropical hardwoods increased 19 times, with three-quarters of the aggregate supply deriving from Southeast Asia. Among all Japan's imports, wood now ranks as a strong second to oil; the country depends on overseas sources for around two-thirds of its wood, a proportion that could rise as high as four-fifths by 1985 (some of the imports stem from North America, but hardwood imports almost entirely derive from the tropics).[9] Hitherto Japan has looked mainly to Southeast Asia for its hardwood needs, but it is increasingly directing attention toward Latin America and West Africa.

Table 1

CONSUMPTION OF TROPICAL HARDWOOD TIMBER: PAST, PRESENT, AND PROJECTED (MILLION m^3)

COUNTRY/REGION	1950	1973	1980	1990	2000
Japan	1.5	28.9	35	38	48
United States	0.8	7.2	10	15	20
Europe	1.9	17.2	21	27	35
Total three importing regions	4.2	53.5	66	80	95
Tropical producing regions	21.0	46.5	66	117	185
Rest of world	1.0	9.0	13	18	23
Total	26.2	108.8	145	215	303

SOURCE: FAO, Forest Resources in Asia and Far East, 1976; and S. L. Pringle, "Tropical Moist Forests in World Demand, Supply and Trade," Unasylva 28 (1976).

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Table 2

SUPPLY OF TROPICAL HARDWOOD TIMBER: ACTUAL AND PROJECTED (MILLION m^3)

REGION	1950 PRODUCTION	1950 EXPORT (%)*	1973 PRODUCTION	1973 EXPORT (%)	1980 PRODUCTION	1980 EXPORT (%)	1990 PRODUCTION	1990 EXPORT (%)	2000 PRODUCTION	2000 EXPORT (%)
Tropical Africa	4.7	1.5 (32)	16.5	11 (67)	20	12 (60)	25	9 (36)	35	10 (29)
Latin America	15.5	0.8 (5)	20	3 (15)	32	4 (13)	60	7 (12)	118	28 (24)
Southern and Southeast Asia	14.3	2 (14)	72.5	48.5 (67)	93	65 (70)	130	82 (63)	150	80 (53)
Total	34.5	4.3 (13)	109	62.5 (57)	145	81 (56)	215	98 (46)	303	118 (39)

*Figures in parentheses are percentage of production given to export.

NOTE: As tropical developing countries themselves start to consume more of their hardwood output, there will be (except in the eventual case of Latin America) a smaller share available for export to developed countries. At the same time, developed countries' demand will steadily expand. So there will be compounded pressure to exploit tropical hardwood forests.

SOURCES: S. L. Pringle, "Tropical Moist Forests in World Demand, Supply and Trade," Unasylva 28 (1976); and other FAO documents.

The United States is the second largest consumer of tropical hardwoods. U.S. demand has been growing at a rate far above the country's growth rates for population and GNP. This has been partly caused by rapidly rising costs of high-quality hardwoods from within the United States, following increased interest in the country's hardwood forests for their esthetic and recreational values. A more important reason is that plywood panelling can be obtained relatively cheaply from Southeast and East Asia; over four-fifths of U.S. imports of tropical hardwoods come in the form of plywood and veneer via Japan—the so-called Philippine mahogany that originates in Southeast Asia. Between 1950 and 1973, U.S. imports of tropical hardwoods increased 9 times (until the country was accounting for about 70 percent of all tropical plywood and veneer entering world trade), and by the year 2000 they are projected to double again.

The nations of Western Europe account for about one-third of the developed world's imports of tropical hardwoods, an amount that is projected to increase by about 75 percent by the year 2000. Most of the timber derives from West and Central Africa, though within the last few years there has been a marked expansion in hardwood imports originating from Southeast Asia.

By far the major source of tropical hardwoods to date has been Southeast Asia (Table 2). Between 1950 and 1973, the region increased its exports 24 times, until it was accounting for three-quarters of international trade in tropical hardwoods. Latin America, with around 3 times as many hardwood stocks as Southeast Asia, currently produces only 10 percent of the world's hardwood timber and exports very little, due to the remote location of many of its hardwood forests. West and Central Africa export only about one-third as much as Southeast Asia. Plainly, however, the progressive depletion of Southeast Asia's forests will cause much greater exploitation pressure to be directed toward the two TMF regions that have hitherto supplied little to international hardwood trade, namely, Amazonia and Central Africa. As harvesting technology allows loggers to extract timber from localities that are currently considered inaccessible because of such factors as difficult terrain or remoteness, and as processing technology enables more heterogeneous types of hardwoods to become acceptable on commercial markets, both Amazonia and Central Africa can be expected to increase their share of the hardwood timber trade.

Paper Pulp

While global consumption of hardwood products is expected to continue to expand, it is paper products for which the greatest growth in demand is projected. TMF contain relatively few stocks of the conventional source of paper pulp, i.e., softwoods. But the international paper trade now expects to depend on TMF for much of its raw materials, as a consequence of recent changes in forestry technology. Until the mid-1970s, it was thought that TMF, with their multiplicity of hardwood species, could not readily be pulped after the manner of softwoods. But new production processes now allow wood chips from some 100 selected TMF tree species to be simultaneously converted into pulp.[10] TMF, comprising some 55 percent of the world's forests, currently produce only 7 percent of the world's paper and paperboard—a percentage that could shortly start to grow rapidly.

During the period 1950-1970 world output of paper products increased from 40 to 130 million tons for a growth rate twice that of population. If long-term trends continue, world demand could rise from its present level of around 180 million tons per year to 400 million tons by the year 2000, and to twice as much again after only a further two decades.[11]

The developed world now uses almost 160 million tons of pulp a year, the developing world little over 20 million. An average developed world's citizen consumes an annual amount of over 155 kg of paper and paperboard (in the United States, 325 kg), while a developing world world's citizen is unlikely to use more than 5 kg. (Many a citizen of Indonesia and Nigeria may not even account for 1 kg, roughly half of one copy of the Sunday edition of the *New York Times*.) If consumption continues to grow as in recent years, the developing world is projected to expand its consumption roughly 3 times, as compared with a 2¾-times increase on the part of the developed world; thus by far the largest share of

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total consumption will remain with the developed world.

Whereas many nations of North America and Western Europe are self-sufficient for paper pulp or even produce a surplus, Japan is heavily dependent on foreign sources, almost half of its pulpwood now coming from overseas. Following recent increases in prices of U.S. softwood chips, Japan is turning to Southeast Asia and tropical America for hardwood chips, which now supply over half of its pulpwood-chip needs.[12]

Even though their consumption rates are presently very low, developing countries are strongly motivated to develop sources of paper pulp. They currently import the great bulk of their supplies, at a 1975 cost of $2 billion—worth almost two-thirds of developing countries' exports of tropical timber. To give an idea of low-level demand in developing countries, and of the amount by which it could expand, total newsprint consumption in 14 Asian countries, including all the most populous ones except China, now totals around 600,000 tons per year, or less than Canada's.

Not only does demand for paper increase with growing human numbers, it expands much more as a consequence of growing human aspirations. In particular, the spread of literacy serves as a powerful stimulus to demand—and in many developing countries, lack of paper is causing serious setbacks to education and communications. Within another decade, there will be a further 150 million consumers of paper in developing countries; by the year 2000, Southeast Asia is expected to need five times as much paper as in 1974. Indonesia, after paying out $92 million for pulp imports to meet 85 percent of its needs in 1977, has a strong incentive to use its own forest resources as a pulp source.

Economic Value

Between 1954 and 1976, tropical wood exports increased in value from $272 million to $4.2 billion. This represents a growth rate far faster than that for global trade in all forest products. Tropical wood exports now amount to around 4 percent of the value of all the developing world's exports excluding petroleum, making it one of the five most important export earners among major commodities produced by the developing world. In fact, tropical wood is now one of the fastest growing exports of the developing world, earning about as much revenue as sugar, cotton, or copper.

Yet, substantial and expanding as these export earnings are, trade in tropical wood nevertheless amounts to only about 15 percent of global trade in forest products. The Congo and Finland have land areas and forest estates roughly the same size, yet in 1973 the value of Finland's forest exports was 60 times greater than the Congo's. The six main countries of the Amazon Basin, plus French Guiana, Guyana, and Suriname, possess 2.7 hectares (ha) of forest per person, compared with a world average of about 1 ha; yet they import more forest products by value than they export.

Ecological Impact

Due to the diversity of tree species in tropical forests, coupled with the reluctance of international timber markets to take more than a small proportion of wood types available, the commercial logger is inclined to harvest very selectively, taking a few choice specimens with disregard for the rest—a "creaming" operation. Of Amazonia's many thousands of tree species, only about 50 are widely exploited, even though as many as 400 have some commercial value. Africa exports only 35 principal species (albeit twice as many as in 1950), with 10 accounting for 70 percent of the total.[13] In Southeast Asia, loggers focus on less than 100 tree species, with exports consisting mainly of only a dozen or so.[14]

So when a patch of TMF is exploited, only a few trees, often less than 20 of 400 per ha, are taken. Yet the logging operation can leave many of the remaining trees damaged beyond recovery—far more than would be the case in a temperate-zone forest—because TMF trees are strongly linked together with vines, lianas, and other climbing plants, sometimes as many as 2,000 per ha and some of them 200 m long.[15] Commercial trees are often limited to the tallest, which, benefiting from the sunlight, develop crowns as widespread as 15 m. When one of these giants is felled, it is likely to break or pull down several

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others with it. Furthermore, tropical trees are highly susceptible to attack by pathogens; as a result, a seemingly minor injury, such as a patch of bark torn off, can leave a tree vulnerable to irreparable damage. Logging roads and haulage tracks, sometimes averaging as much as 10 km for each km^2 of forest exploited, can, together with dumping zones and land for logs, account for 10 to 30 percent of the forest area.[16]

Repeated surveys in Southeast Asia reveal that the average logging operation leaves between one-third and two-thirds of residual trees damaged beyond recovery.[17] In addition, almost one-third of the ground may be left bare, in many instances with the soil impacted by the heavy machinery.[18] With greater care, the damage could be reduced by half. But less destructive exploitation would raise timber prices for the end-product consumer—something that the main markets (developed nations) are unlikely to accept on the grounds that it would be unduly inflationary.

Clearly, logging impact varies from area to area. In some places, the consequence is only light modification of the forest, while in other places it amounts to gross degradation. If the logging is highly selective, e.g., for mahogany, it is possible that the forest may never return to its original composition. Even if the logging is less selective, it will still take many more than a few years for natural regeneration to fill the gaps caused by the removal of timber trees.[19]

Wood Chips

Forestry technology has recently developed processing methods that enable tropical hardwoods to be pulped in a single mixture.[20] In Colombia, some 100 species are used in one operation, subsequently supplying 40 percent of the kraft and linerboard. In Papua, New Guinea, a joint hardwood chip mill, established in 1974, accepts over 200 species at once. Similar operations are under way in Brazil, Indonesia, Malaysia, the Philippines, and Thailand. Since the techniques cannot only be applied to sound trees of any sort, but can be used to salvage defective trees and dead standing timber, they can expand the yield of a hardwood forest by as much as an additional 300 percent of usable wood.[21]

Thus the extreme heterogeneity of TMF no longer presents a problem to the forest exploiter who seeks to manufacture wood pulp. This represents a welcome breakthough not only for Japan, with its large and growing demand for wood chips from overseas, but also is of potentially enormous benefit to tropical-forest countries themselves, with their fast growing need for wood pulp.

Furthermore, some observers look upon this "any-tree/all-tree" harvesting, also known as full-forest harvesting, as an innovation that could represent some sort of salvation for TMF, at least so far as certain forms of wood exploitation are concerned. By enabling intensified production of wood products in a few selected areas, it could relieve extensive harvesting of wood from large tracts of forests. Other observers are inclined to believe that it could amount to a two-edged sword. Under this technique, a patch of forest is not exploited selectively, on a sustained-yield basis; segments are exploited entirely, once and for all.

However, if a harvested forest is then replaced by a man-made forest, this intensive use both of the original forest and of the land on which it stood may help to confine timber harvesting to limited localities. Alternatively, full-forest harvesting can be conducted in scattered blocks, or in strips possibly up to 200 m wide (although no experimental studies in tropical forest management have shown 200 m to be the upper limit of clear-cut strips), whereupon the surrounding tracts of undisturbed forest will eventually enable the exploited zone to regenerate. But this sophisticated harvesting technique can work to ways: it can either hold out better prospects for many sectors of untouched forest, or it can presage total conversion for many sectors.

Plantations

In a few localities of the tropics, forest plantations are being established. These plantations now comprise around 85,000 km^2. Of this total, almost 40,000 km^2 are in Latin America (over half in Brazil), and the rest split between southern and Southeast Asia, and West and Central Africa.

OAS

AID

Seedlings to supply firewood being grown in the Kombissini nursery in Upper Volta.

To the extent that man-made forests supply the quantities and types of wood required by world markets, they reduce the pressure to exploit primary forests. So fast-growing are some plantation tree species that a 500-km² plantation can readily produce 1 million m³ of marketable timber per year, a volume that could be obtained only from 10 times as large an area of natural forest.[23] However, only 5,000 km² or so of additional plantations are established each year—only one-third as many as would be required to supply enough wood to relieve extreme exploitation pressures on TMF during the course of the next two decades.

In any case, tropical forest plantations are not without problems. They can prove costly to establish, $200 to $400 per ha. In common with many monoculture crops, they tend to attract diseases and pests that are numerous and varied. When plantation trees are harvested, they may take a large stock of nutrients with them, requiring the use of ever increasing amounts of fertilizer to maintain productivity.

The greatest expanse of tropical plantations, some 25,000 km², is in Brazil, one of the world's most impressive forestry accomplishments. Less than 1,000 km² are located in Amazonia, with the rest in southern Brazil, where broad-leaved species are grown on 13,000 km² and conifers on 10,000 km².

In 1975 Brazil consumed 1.9 million tons of paper, an amount that is expected to reach 4 million tons by 1985. Although Brazil is now among the world's 10 leading pulp producers, it imported 700,000 tons of pulp and paper in 1974, worth $349 million.[25] As a result of its plantation program, established in the mid-1960s, Brazil aims to produce enough pulp to meet its own needs by the early 1980s, and by the year 2000, Brazil plans to have an annual surplus of 20 million tons of pulp for export to other countries of Latin America (worth at present prices, $5.5 billion).[26]

This long-term program will require an additional 40,000 km² of plantations. During the 1970s, the average price of land for reforestation in some of Brazil's heavily populated southern areas has increased 11 times, so there is strong incentive to look for opportunity elsewhere—notably in Amazonia, where there are scheduled to be 10,000 km² of plantations by 1985. Nonetheless, even if all additional plantations of the next two decades were to be located in Amazonia, they would not have to affect more than 1.5 percent of the present forest expanse.

Obstacles

From the standpoint of safeguarding primary TMF, the most appropriate strategy is to establish plantations in forest territories that have already been exploited and have become poor-quality secondary forest, degraded grasslands, or areas that have been overburdened by forest farmers. There are 440,000 km² of such misused lands in Indonesia alone—an area larger than the country's designated protected forests. A number of pioneer tree species can be made to grow satisfactorily in such areas.

Regrettably, an outcome of this sort is generally precluded by at least two factors. First, a plantation entrepreneur seeks to locate his concession within an extensive tract of primary forest, so that he can exploit the hardwood timber to capitalize his plantation. Secondly, already cleared forest-lands are generally occupied by settlements of one sort or another, and it is politically difficult to uproot these in order to plant trees.

A further problem arises, one that could severely reduce the expanse of plantations to be established anywhere in TMF countries. This concerns the scale of investment that will have to be made available for plantations (plus associated processing industries) if they are to make a sizable contribution to tropical timber supplies during the foreseeable future. Food and Agricultural Organization and World Bank estimates run as high as $3 billion per year over the next two decades.

In the face of investment requirements of this magnitude, TMF countries are increasingly looking toward the foreign investor: half of Latin America's total sales of paper and paperboard have recently been accounted for by affiliates of U.S. timber corporations;[27] and Brazil has just reached agreement with 11 Japanese companies for a $1 billion, 4,000-km² pulp project. Yet foreign investors are not moving into the field of tropical plantations as fast they might. They are not sufficiently assured concerning security of prices for their products, or security of tenure for their holdings.

Each inflationary upheaval in world currency systems, and each nationalization of a foreign enterprise in a tropical country, defers the day when enough plantations will be established to relieve the more excessive timber exploitation pressures on TMF. Considering that plantations require a lead time of at least 10 years before they start to produce wood in bulk, stabilizing a favorable politico-economic environment for the foreign entrepreneur is an urgent requirement.

NOTES

1. For further information on the potential value of tropical species see Norman Myers, "Conserving Our Global Stock," Environment, Nov. 1979, p. 25.

2. Despite the exceptional ecological and economic value of the tropical moist forest biome there is no standard and objective definition of "tropical moist forests." The definition of tropical moist forests (TMF) I have used here is as follows: "Evergreen or partly evergreen forests, in areas receiving not less than 100 mm of precipitation in any month for 2 out of 3 years, with mean annual temperature of 24+ °C and essentially frost-free; in these forests some trees may be deciduous; the forests usually occur at altitudes below 1,300 m (though often in Amazonia up to 1,800 m and generally in Southeast Asia up to only 750 m); and, in mature examples of these forests, there are several more or less distinctive strata."

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Trucks remove timber from jungle in the State of Pahang, West Malaysia.

World Bank/Mary M. Hill

ASPECTS OF LAND AND WATER MANAGEMENT

1. "Using Natural Resources as a Planning Guide"
2. "The Ganges Water Machine"
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4. "Alternatives to Pesticides in the Southeastern United States"
5. "Integrated Pest Management in China"

Source: Rural and Small Town Planning,
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Chapter III
Using Natural Resources as a Planning Guide

Rural areas are fortunate in still being able to make planning choices based on existing natural resources. Although it would appear self-evident that choices must be based on the land in rural areas, the method of land-use planning that starts with the natural resource base is sometimes overlooked by planners trained to deal with urban situations where the possibility of making such choices has long since disappeared. In recent years, increasing numbers of rural areas have recognized their special opportunities and have developed planning methods which take natural resources as their starting point.

Planning based on the natural resource base is motivated not only by the desire to conserve and protect desirable natural features (although this is of course an important point), but also by a belief that development of any kind—roads, residences and shopping centers—can best be located, with less present expense and fewer future problems, if based on an understanding of natural constraints. The natural environment can structure the optimum location of development and save the community problems in the future—problems with provision of water, for example, or with erosion, settling, and sedimentation. Once the natural characteristics of the land are mapped and classified, a clear physical structure which constrains or permits future growth often becomes apparent.

Preparing the inventory and classification of natural resources is an important part of rural environmental planning. Out of the variety of existing characteristics that can be looked

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at, the planner selects for analysis those which will have the most important effects on future development. It is clear that topography, soils and water are important. Topography dictates the location of roads and houses; clearing steep slopes for building is not only expensive but may create future problems affecting the stability of larger land areas. Soils have important characteristics which must be respected: permeability relates to the location of septic systems; bearing capacity affects the costs of new housing, and preserving agricultural potential may be necessary for the economic health of the community. Though it is hardly necessary to point out the value of a pure water supply, the relationships between the supply of water and other characteristics of the natural resource base are not always obvious. A natural resource inventory can help to point out important relationships between the various natural and man-made systems. Geology, vegetation, wildlife, and unique natural or man-made features all play different parts in maintaining the desired quality and unique identity of a given region.

This chapter provides a guide to some of the techniques involved in preparing the inventory of existing conditions, offers some aids to the planner or citizens making the inventories, and suggests some of the characteristics of existing resources which must be examined and interpreted.

Maps

A useful resource inventory is compiled by describing and mapping each set of natural features and existing land uses individually: topography, hydrology, soils, geology, vegetation, and wildlife are suggested as basic categories for maps. Other natural resource categories, however, may be selected. The primary sources of information will be existing maps, verified by field checking where possible, supplemented by reports, studies, and surveys.

It is important to keep in mind that along with maps and other printed documents, there is no substitute for firsthand information: local specialists such as hydrologists and geologists at nearby universities are frequently the most expert sources of

information in a region. Not only will they be able to interpret configurations, statistics, and other data, but they will probably have recent information and field experience. Agencies working with maps should maintain close contact with those who compiled and published the maps. For example, any decisions based upon soil, geological, or topographic considerations should be made only after consultation with the regional offices of the Soil Conservation Service of the U.S. Department of Agriculture. Aside from their ability to interpret maps, they will have updates and amendments on hand.

Maps will be of little use unless they are able to be interpreted and evaluated easily. The identification of sub-areas for their intrinsic suitability for conservation or for future development might be the guiding principle in preparing a presentation. For each of the major data categories, factors related to *conservation* or to *development* should be selected and highlighted. For an initial planning effort a simple summary categorization of data will be helpful. For example, in presenting an interpretive map of slope conditions, 'slopes greater than 25 percent—usually no development" may be represented by dark shading; "slopes from 15 to 25 percent—suited for development" and "slopes of 0 to 3 percent—acceptable for development if no ponding or erosion problems" should be shaded successively lighter. By such a presentation, major categories will be clear. What is important is to recognize that too much data may be as difficult to understand as too little. For purposes of clarity, or to highlight a variety of values, it may be useful to prepare more than one interpretive map for a given category. For example, a soils map may be prepared which highlights soils suitable for agriculture, and one which highlights soils suitable for construction.

Since each set of data (e.g., soils) should be recorded on its own map, it is essential to have a good base map, which acts as a reference point upon which subsequent maps are placed. Base maps should display all man-made features in the region: roads, political boundaries, and even individual structures, if the scale is small enough to permit it.

The base map should be of a convenient size for work in the field, and easily reproducible. It is important to keep it simple

and legible. Scale should relate to the capabilities of reproduction equipment readily available. If the map is to be reproduced in sections to be pasted together it should be divided in such a way as to make matching easy. Sections should also be divided in such a way as to be easily reproducible on available equipment. If maps are to produce maximum benefits, they should be readily available and relatively inexpensive.

It may be useful to have a base map prepared in two or even three different scales or sizes in order to meet all eventual demands. For all towns but those of very small size, it may be desirable to have a base map with sheets at a scale of 1" = 200" or less for central areas which are densely settled. For areas which are developed with a number of 50-foot lots, a scale of 300 to 600 feet to an inch is about the minimum for acceptable legibility. For a rural area which wishes to include a central village with extended environs on its base map, ability to measure within fractions of a mile is all that is needed. In this case 1,000 feet or a half mile to the inch will be appropriate. The final choice will depend on the size of the community and its particular needs. Combining maps of several scales for the preliminary survey may be the most workable procedure.

The U.S. Geological Survey (USGS) maps at a scale of either 1:24,000 1" = 2,000 feet ($7\frac{1}{2}$ minute) or 1:62,500 (15-minute) 1" = approximately 1 mile (the former being more accurate than the latter) are convenient and useful references. Land Use and Land Cover and Associated Maps are now being compiled by the USGS for the entire country.

In 1974 the National Cartographic Information Center (NCIC) was established by the USGS to provide information and assist data users in obtaining both general and special cartographic information. They are an excellent source of help.

Topography and Slope

Land use is determined, to a great degree, by elevation and slope. Historically, development progressed through lowlands, into valleys, and around hills and mountains. Although this general pattern still remains true, today there are far fewer

restrictions on developing steep slopes and other areas once considered inaccessible or undesirable. For this reason, the shape of the terrain must be known if land use is to be properly planned. As elevation increases, so do the costs of roads, utilities, and maintenance services, such as snow removal. As the degree of slope increases, so does the difficulty of building and supporting structures.

The development of hillsides must be approached with care because such development can affect the equilibrium of a region or district wider than anticipated. Care must be exercised when tampering with the harmony of slope, soil, vegetation, drainage patterns, and geological foundation.

Bad planning can disturb soil stability, causing erosion and a resulting loss of slope; careless removal of vegetation from hillsides deprives the grade of the cemental network of plant roots, alters established drainage pathways, or eliminates a natural wind screen. Such a loss of protection permits rapid erosion, which adds silt and other sediment particles to downstream waterways and sullies immediate water quality. Spring thaws or strong rains on unstable slopes can produce mass movements, such as landslides, slumps, and flaws, particularly in steeply sloping areas.

By the removal of vegetation, hillside development also increases runoff that would ordinarily be retained and transpired by trees and other vegetation. The detrimental effects of hillside disturbance are increased by the addition of impervious surfaces, such as paving and buildings, further reducing groundwater percolation, thus adding to the amount of runoff, destruction of water quality, and potential for flooding.

Furthermore, disturbance of hillsides can destroy a community's aesthetic resources. A range of hills frequently marks a community's boundary and provides an attractive scenic setting for homes and buildings. Degradation of hillsides as a result of erosion and loss of vegetation deprives a community of its attractive and distinct setting and decreases real estate values.

Through insufficient attention to the problems posed by erosion, runoff, and aesthetic damage, hillside development can have a far-reaching impact on a region's land, water, economic, and scenic resources. Yet with proper planning,

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hillsides can be developed in a manner compatible with hillside ecology.

Although there are many factors that determine where hillside development is appropriate, it is safe to say that low slopes (those with 1 to 10 percent grade) offer few major obstacles to development, although they are susceptible to erosion if careless removal of the groundcover occurs. Gentle slopes are capable of supporting low-density residential use, but more intense uses should be allowed only with caution.

Density should be lower on moderate slopes (10 to 25 percent grade) because severe erosion and land slippage may result when the groundcover is disturbed. Subsequent sedimentation is a serious possibility, fouling and clogging streams and disrupting the natural water courses. If the soils and drainage on moderate slopes are not conducive to construction, structural damage can result.

On extreme slopes (above 25 percent grade), development will almost certainly increase the amount and velocity of runoff, causing severe erosion. Since development is risky and very expensive, these areas might be set aside for recreation since they often are of great scenic beauty.

Slope in a region may be determined from a topography map, readily available from the National Topography Map Series of the USGS. Most states now have a complete coverage at 1:24,000 and 1:62,500. Relief is shown by 20-foot contour lines on 15-minute maps and 10 feet on $7\frac{1}{2}$ minute maps. If the use of contours is wanted for an overlay map, the USGS can furnish maps with only the brown overprint that indicates contour lines.

Other sources for topographic maps in some states are state geological surveys and state planning agencies. In addition, the U.S. Army Topographic Command has maps for some areas of the country. Soil survey maps usually provide some topographic information—mainly that relevant to erosion, location of ridge lines, and direction of drainage. If an area lacks current maps, the USGS will pay up to one-half the cost of topographic mapping carried out in cooperation with state or local governments.

It will be easy to use contour maps for public presentation if, instead of using an overlay of contour lines, the degrees of slopes are aggregated into three or more groups—low, moderate, extreme, etc.—and each assigned a different color. This will at once reduce the complexity of the map and, at the same time, highlight only those areas that have significant slope that will have an effect on planning development.

Hydrology

The principal reasons for controlling development on or near water are to protect watersheds, to preserve the quality and quantity of the water supply, and to prevent damaging floods. Urban areas require great quantities of water for industrial, business, and domestic use. In regions where agriculture is a major land use, water availability and quality are as important as soils. Since, in any case, surface waters are essential for regional aesthetic and economic benefits, they should be inventoried thoroughly.

The desired degree of control varies for the type of area where development would affect surface water. Permanent bodies of water—lakes, rivers, streams, estuaries, etc.—are valuable as a source of water supply, food, and recreation, for waste dispersion, transportation, and power generation. All lakes and ponds may become degraded, become marsh and then dry land. This natural evolution, called entropy, may be hastened by uncontrolled development since pollution and erosion resulting from urbanization can destroy the water's balanced nitrogen and oxygen cycles and its recreation potential.

Streams and creeks have a direct effect upon the quality and quantity of a region's water resources. Qualitatively, streams and creeks replenish groundwater, river flow, and reservoirs; they are a major natural source of water to the system and if they become polluted, then a region's entire water resource, both above and below ground will suffer. Quantitatively, streams and creeks may carry increased runoff or sediment from improper watershed development and increase or cut off regular water flow to groundwater formations. Similar quantitative effects can be seen, on a larger scale, in lakes and rivers.

Since streams and creeks contribute to a region's total water resource and general environmental well-being, the planning of development within a region must expand beyond the watercourses themselves and look to the whole concept of the watershed system—drainage, wetlands, lakes, reservoirs, and groundwater filtrations. Since streams and creeks are major networks that transport nutrients and sedimentation, as well as pathways functioning as routes for various birds and mammals, they are a matrix of the watershed, binding hillsides, woodlands, and wetlands into one inseparable, interdependent ecological community. Because streams and creeks are an intricate part of the hydrological and nutrient cycles, and because of their intricate relationship to so many environmental communities and processes, the health of the watercourses serves as an index to the health of the entire system.

Floodland is the land area adjacent to a body of water which is covered by excess water during periods of flooding. This water carrying capacity of floodlands is an essential function and is why floodlands are so valuable. Floodlands may be divided into zones based on the frequency of inundation, often categorized as channels, floodways, and floodplains. It is especially important to make these distinctions for land-use and development controls which are important since building on floodlands endangers human life and property. Furthermore, floodplains often provide valuable recreation land. Filling, damming, or leveling floodplains decreases storage capacity and increases flood velocity and the flood potential downstream. Agriculture is often an ideal use in floodplains as the soils are very fertile, there is usually substantial groundwater, and the effect on flat land is minimal.

Wetlands—tracts of low-lying lands that are saturated with moisture and usually overgrown with vegetation—act as sponges that absorb excess runoff and thus reduce flooding potential. They also provide important wildlife habitats and recreational areas and have educational and scientific value. Some wetlands have agricultural value; they often have scenic beauty. Wetlands are frequently found about estuaries—water passages where the tide meets a river current, especially an arm of the sea at the lower end of a river. As breeding

grounds for a variety of organisms, estuaries are particularly intolerant of waste disposal, dredging, filling, and upstream pollution since these activities can destroy important animal and plant communities.

Subsurface waters in the form of aquifers—water-bearing layers of sand, gravel, or porous rock—are as important and delicate as surface waters. As a major source of water supply, their quality must be maintained and the removal of water from them must not exceed the rate of replenishment. Aquifers are replenished in recharge areas—areas of interchange between the aquifer and the earth's surface and the point where precipitation and surface water infiltrate the aquifer. Wise planning of development in recharge areas is particularly important because of the danger of polluting the water supply.

Aquifers act as reservoirs, filters, and a balance in the hydrological system of a community and region. They are natural reservoirs for groundwater used in drinking and irrigation and must be protected because the amount of groundwater entering the aquifers is used by many types of communities: some areas can draw upon surface water supplies, such as lakes and streams, for their drinking water and irrigation needs, but many communities, particularly rural ones,depend upon groundwater or wells drilled into aquifers for their water.

Percolation of precipitation through soil and overlying formations filters many impurities before they reach the aquifer; as groundwater moves through waterbearing formations of aquifers, it is filtered further. But this filtering property of aquifers is not absolute. Leaking septic tanks and sewage lines, unsealed landfill sites, and sewage and soil waste disposal sites can allow pollutants to pass directly into groundwater reserves where the water table is very near the surface, the soil mantle is very thin, or the aquifer is very permeable. In these cases, concern must be directed toward the quality of water entering the aquifer.

Similarly, pollution or depletion of surface water affects groundwater and can contaminate an entire system since aquifers are directly connected to lakes, streams, and wetlands through gradual seepage. Alternately, some of these lakes,

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streams, and wetlands replenish their water supply from the aquifer when conditions are dry. Therefore, pollution factors must be checked to maintain the aquifer-stream-lake-wetland reciprocal balance and attention must be focused on the quality and quantity of water exchanged between groundwater and surface reserves.

Because aquifers serve these three functions—they act as a reservoir, as a filter, and as part of the hydrological cycle—they are important regional resources and are particularly sensitive in terms of development. It is best to avoid development over deep aquifers.

Hydrology studies include subsurface water as well as surface water. The Water Information Group of the USGS has information in the form of maps, atlases, and reports that cover various characteristics of the hydrological cycle. They have a free publication for each state, "Water Resources Investigation," which includes a list of a selected number of reports prepared for each state. Depending on detail, the scale of the maps varies from 1:24,000 to 1:250,000. For surface water only, a local planning agency may request a copy of the blue overprint from the standard USGS topographic map. These hydrological maps and reports containcmuch information about the quality and quantity of ground and surface waters. For a given area, hydrological information includes analyses of the elevation levels of major floods, depth to mineralized groundwater, saline water, chemical qualities of surface water, and temperature of surface water. Aquifers, floodplains, and wetlands should be highlighted on the hydrology map.

Soils

Soil composition directly affects building and highway construction, septic systems, water availability, and agriculture. Since everything that touches the soil is affected by it, it is essential that accurate soil data are used in land-use planning. A soil suitability study should be used to assess (1) the engineering property of soils in order to determine the appropriate pattern of residential, commercial, industrial, agricultural, and

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recreational use; (2) the suitability of soils for sewage dispersion, drainage systems, and water storage; (3) the soil and plant relationship so that prime agricultural areas can be identified; and (4) the location of important mineral deposits.

Soils with a high moisture content, whether due to a high water table or poor drainage, are suitable only for floating or other specially built structures if supplied with public water and sewerage. Wet soils, important because they store water, can be easily contaminated if septic tanks are allowed. In development, draining and filling should be permitted selectively if they do not interfere with the water supply.

Dense soils inhibit and are often impervious to the free downward flow of water; such soils usually have a high proportion of clay in them. Impermeability may cause tanks to overflow and contaminate the water supply, and like wet soils, dense soils are unsuitable for development without public water and sewer systems.

Poor load-bearing soils are usually easy to compact because of their moisture content or because excessive internal spaces are present. (Filled land or industrial or municipal waste piles often have these characteristics.) Such soils are unable to support structures such as buildings and paved roads, and are thus generally unsuitable for intensive development. Recreation and agriculture, as well as certain types of light or flexible structures, are adaptable to poor load-bearing soils, but heavy structures require anchoring to bedrock.

If a local planner is unable to interpret soil types into appropriate use categories (e.g., soils good for residential development, soils for agriculture), the local Soil Conservation Service (SCS) office can prepare such interpretive maps and reports. For this reason, it is a good idea to work closely with the local office.

A soil survey is based upon aerial photography and the maps are usually printed at a scale of 3" = 5,000 (3:60,000) or 1" = 1 mile. They are accompanied by a discussion of the functional classification of the soils in the area based upon a nationwide classification system, including a description of each kind of soil and general information about the agriculture and climate of the area. Most surveys supply information such as the most

important soils for potential agricultural uses, what types of wildlife are likely to be associated with certain types of soils, nonagricultural plant material and its relationship with soil types, likely flood and drainage areas, and soil properties affecting engineering uses. This basic information provides a suitable foundation for planning decisions.

Geology

Geology involves not only bedrock and other mineral foundations covered by a layer of soil, but also areas and planes of exposed rock. Geology has a fundamental bearing upon surface and subsurface drainage patterns and a site's ability to support structures.

In some areas, the underground formations are incapable of supporting heavy loads and development can cause subsidence, landsliding or other earth movement. These weak areas are usually associated with certain geologic characteristics, a type of bedrock or the manner in which layers of rock and soil are arranged, for example. Areas such as these may be capable of supporting only low-intensity development and may require special construction methods to assure slope stability.

Many problems arise because investigations often neglect to identify the nature and location of subsurface mineral deposits. Wherever mineral extraction is feasible, the detrimental effects of such extraction must be minimized and provisions must be made for site re-use after the extractive operations are concluded. With proper planning, mineral extraction can be accomplished without negative effects on the environment, but this is possible only if planners know beforehand where the deposits are located so that land use before and after the operation can be controlled. If mineral deposits are found after development has taken place, extraction operations must be precluded.

One of the problems encountered when collecting geological data is that too often they are outdated and have varying degrees of accuracy in many areas of the country. Furthermore, interpretation requires experts. Geological maps of

1:24,000 to 1:63,363 are available for only about 25 percent of the U.S. and smaller scale maps (1:250,000) are available for less than one-third of the states and approximately 40 percent of the country. Maps showing geological structure and mineral resources in a region are available from the USGS.

Vegetation and Wildlife (Biotic Resources)

Too often, if vegetation and wildlife are considered at all in land-use planning, it is only in terms of parks and other open spaces for recreation. Little thought is given to the ecologically delicate relationship among plants, animals, and man. Since uncontrolled development and the subsequent loss of groundcover can often have serious consequences, it is important that planners should have at least a working acquaintance with ecology and should gather as much information as possible about areas in their region sensitive to development.

Development should be watched especially in woodlands since they play an important role in the protection of watersheds. Aside from the aesthetic pleasures that trees, shrubs, and other vegetation provide, they also prevent erosion by binding the soil together with their roots. In addition, as water percolates downward, plantlife aids in its cleansing.

Unique vegetation habitats should be preserved for scientific and educational reasons. Virgin stands of forest, unbroken prairie, and other features support complex animal communities that are intrinsically important. The tolerance of these areas to intensive nearby development varies but must be taken into consideration in any event.

The green overprints of the USGS topographical maps may be used to determine dense woodland cover, but for a more detailed and accurate inventory, local sources have to be used. Wildlife and botany experts at nearby schools are often valuable aids for identifying unique habitat areas and routes of migratory animals that are worthy of protection. State fish and game departments may also have to be consulted. In short, gathering data on vegetation and wildlife is a piecemeal process. Site-specific information on biotic resources simply does not exist for most regions.

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The Ganges Water Machine

Roger Revelle and V. Lakshminarayana

The river Ganges and its tributaries, and the flat and fertile plain through which they flow, are one of earth's great natural resources. For thousands of years abundant water and generous land have provided the foundation for a highly developed civilization based on agriculture and for one of the world's largest concentrations of human populations. But farming is mainly traditional and at a subsistence level, with little surplus, and as a result the population has remained overwhelmingly rural and most people are desperately poor. Although irrigation from canals and wells has been practiced for millennia, chiefly as a protection against the uncertainties of the monsoon rains, the water resources are largely untapped; the small fraction of water used for irrigation is poorly managed and its productivity is low.

Deeply embedded cultural, social, and economic problems inhibit modernization of agriculture and fuller utilization of the water resources. Capital investments and technological changes on a large scale are also required. As experience elsewhere shows, the introduction of technological changes on the required scale might break the chains of tradition and injustice that now bind the people in misery and poverty.

Ganges and Its Tributaries

The Ganges Basin covers parts of four countries, India, Nepal, Tibet, and Bangladesh; eight Indian states, Punjab, Uttar Pradesh, Haryana, Himachal Pradesh, Rajasthan, Madhya Pradesh, Bihar, and West Bengal; and the Union Territory of Delhi. We shall consider that part of the Basin that drains into Bangladesh through the great distributary called the Padma. The other main distributary, called the Bhagirathi, has long been moribund and now serves only as a spill channel for Ganges floods. Within India, the Ganges Basin, as we have defined it, covers 800,000 square kilometers (*1*). Its population is about 225 million, somewhat more than that of the United States, which covers nearly ten times the area. At present rates of growth, the population will double in 30 years.

The fundamental problems of land and water development in the Ganges Plain arise from the highly seasonal flow of the river and its tributaries. Nearly 84 percent of the rainfall occurs from June through September, and 80 percent of the annual river flow takes place during the 4 months of July through October.

The average annual flow of the Ganges at the Hardinge Bridge in western Bangladesh is 36.2×10^6 hectare-meters, and the monsoon flow from July through October is 28.9×10^6 ha-m. During the remaining 8 months of the year, the river carries only 7.3×10^6 ha-m (*2*). Part of this dry-season flow comes from groundwater in the Ganges Plain, and the remainder comes mainly from the Himalayas.

Even at present, the dry-season flow of the Ganges is barely sufficient for the needs of India and Bangladesh. If irrigation with either groundwater or surface water continues to be developed along the lines of present programs, the dry-season flow will be continually reduced. In order to develop the full irrigation potential of agricultural land without unacceptable reduction of the dry-season flow of the Ganges, it will be essential to store a portion of the monsoon waters for use in irrigation. Because of the steep slopes of the Himalayan foothills and the flatness of the Ganges Plain, surface sites for storage are scarce, and costs per unit volume of surface-stored water are several times higher than in many other parts of the world. On the other hand, there are great possibilities for underground storage, which should be relatively inexpensive.

Present Needs for the Ganges Low Flow

Irrigation in Bangladesh. The average rainfall in Bangladesh is higher, and the potential for increasing groundwater recharge from rain is greater, than in the Indian part of the Ganges Plain. Unfortunately, there is a wide variation among different districts, just as in India. Revelle and Herman (*3*) estimated that water from the Ganges is needed in Bangladesh during the low flow season to supplement groundwater irrigation in three districts in the northwestern part of the country. In the southwest, where the groundwater is saline, Ganges water is the sole irrigation source. In other districts some Ganges water is needed to minimize saltwater intrusion. The sum of these needs totals about 1.8×10^6 ha-m.

Diversion of low flow waters for Calcutta port maintenance. Part of the Ganges waters during the low flow season must be diverted at the Farakka Barrage through the Bhagirathi into the Hooghly River, to maintain a sufficient freshwater discharge past the port of Calcutta. We learn that the feeder channel at the Farakka Barrage has been designed and constructed for a capacity of about 0.29×10^6 ha-m per month. This is more than half the average low flow of the Ganges during the 3 months of February through April. These are also the months when the need for surface water is most critical in western Bangladesh and when the flow into the rivers from groundwater is minimal.

Navigation on the main stream. Economic development in both India and Bangladesh would be hastened if the Ganges could be used as a great international waterway for transport of heavy or bulk materials. Conversely, as development proceeds, the needs for year-round water transportation on the river will rapidly grow. A water route down the Ganges and up the Brahmaputra into Assam would yield large benefits today.

Year-round transportation will depend directly on maintaining a sufficient dry-season flow. Even for relatively shallow barges and moderate-sized ships, an average river depth of 5 m would be desirable. With a width of 900 m and a velocity of flow of 0.35 m per second, this would require a minimum discharge of 1550 m^3/sec, or about 3.2×10^6 ha-m during the eight dry months.

Downstream water quality. The growth of modern agriculture in India,

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based on irrigation development, and the construction of heavy industries with large water demands will inevitably worsen the quality of the Ganges waters during the low flow season. A large variety and quantity of chemical and organic residues, including chemical fertilizers and pesticides, will be carried in the return flows to the rivers. Although it is difficult to make a quantitative estimate of the amounts that will be involved, one of the most forceful arguments for maintaining the low flow is to ensure that a sufficient volume of water remains in the rivers to dilute and oxidize these residues.

Utilization of Monsoon Flows

Taking into account the irrigation potential in the kharif (monsoon) and rabi (winter) growing seasons, at least 25×10^6 gross cropped hectares in the Ganges Plain could be fully irrigated in addition to the present partially irrigated gross area of about 12.5×10^6 hectares. With modern agricultural technology, the production of food grains from the irrigated area could be more than 150×10^6 metric tons, enough to provide a satisfactory diet for more than 600 million people. These possibilities can be realized, however, only by integrated development of the surface and groundwater resources of the Ganges Basin. The time required would be of the order of 25 years, but benefits from projects which would be compatible with the integrated system could be obtained at every stage.

The key to successful development will be storage and beneficial use of a major part of the monsoon flows of the Ganges and its tributaries, which now run to the sea largely unused. Utilization of these high flows for irrigation throughout the year would have a further advantage in ameliorating flood damage (*4*).

In the past, irrigation development in both the kharif and rabi seasons has been largely based on diversion of the river flows and on utilization of a portion of the underground waters which would otherwise seep back into the rivers. The low flows of the Ganges and its tributaries are being progressively reduced, even though the present river volume during the 8 months of the dry season is just about sufficient for municipal and industrial water supply and waste disposal, maintenance of water quality, diversions to protect the port of Calcutta, needs of Bangladesh including prevention of salinity intrusion, and future needs for navigation.

Besides the limited possibilities for surface storage, there are at least five ways in which a portion of the monsoon flows could be stored underground. Infiltration into the water table in the monsoon season could be increased by (i) water spreading in the piedmont deposit north of the Terai belt of springs and marshes; (ii) constructing bunds at right angles to the flow lines in uncultivated fields to slow down runoff and increase infiltration; (iii) pumping out the underground aquifers during the dry season in the neighborhood of nallahs (natural drains) which carry water during the monsoon (*5*); (iv) pumping out groundwater during the dry season along certain tributaries of the Ganges to provide space for groundwater storage; and (v) increasing seepage from irrigation canals during the monsoon season by extending the network of canals, distributaries, and water courses for kharif irrigation and pumping out this seepage water during the dry season. In addition, evaporation losses from the water table might be reduced by lowering it below the level of appreciable evaporation. Finally, it may be beneficial to export some monsoon water from the Basin to the areas to the south and west where irrigation could be extended if firm water supplies were available.

In Table 1 we have estimated the likely increase in irrigation water supplies produced by some of these devices. A large increase could be obtained by construction of barrages and "leaky" canal systems for surface irrigation of a large part of the cultivated area, including an increased area of rice cultivation, during the kharif season, plus wells to recover the underground seepage during the rabi season. Recharge of aquifers along certain Ganges tributaries could provide an equally large increase of rabi irrigation supplies.

Possible use of aquifers near rivers to store monsoon water. There is good reason to believe that in many places the underground aquifers are well connected to the rivers and are highly permeable. For example, in one region where a groundwater survey was made (*6*) the seasonal contours of the water table on both sides of a large tributary show that this river is a drain which carries off perhaps 0.12×10^6 ha-m of water that seeps into it during the dry months from the underground aquifers. If these contours could be reversed by large-scale pumping of the underground waters in the dry season, the aquifers could receive and store a large part of the monsoon flow of the river. We believe that similar underground storage of river floodwaters could be carried out along many tributaries of the Ganges.

It would be necessary to lower the

Table 1. Possible future water budget for the Ganges Plain. Except where noted, values are calculated from data in *Report of the Irrigation Commission, 1972* (*1*).

Source or sink	Volume ($\times 10^6$ ha-m) during Low flow season (November to June)	High flow season (July to October)
Supplies		
Present average river flow at Bangladesh boundary	7.3*	28.9*
Evapotranspiration from present surface storage and river diversion (1968–1969)	1.8†	1.8†
Evapotranspiration from present well irrigation (1968–1969)	1.3†	0.7†
Additional surface storage (under construction or potential)	1.5	−1.5
Reduction of groundwater evaporation by pumping down water table	0.8†	
Increased infiltration of rainfall by bunding in uncultivated areas	0.7†	−0.7†
Potential additional underground storage	6.0‡	−6.0‡
Transfers out of basin (such as "Ganga-Cauvery Link")		−1.8
Total supplies	19.4	21.4
Uses and excess flows		
Consumptive use in present irrigation (1968–1969)	3.1	2.5
Consumptive use in potential additional irrigation	9.0†	6.0†
Diversion to Hooghly River at Farakka Barrage for Calcutta maintenance	2.3‡	
Needs for irrigation in Bangladesh	1.8‡	
River navigation and waste disposal	3.2‡	
Monsoon flow at Bangladesh boundary§		12.9
Total uses and excess flows	19.4	21.4

* From (*2*). † See (*9*). ‡ See text. § Estimated by differences.

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water table to a greater depth at the beginning of the monsoon season than that required simply to produce the storage volume. Moreover, the aquifer directly under the river would need to be pumped down close to the average depth. In the rivers of the western part of the Plain, where the dry-season flow comes largely from groundwater seeping out of the river banks, the low flow discharge during the first year would be removed by the pumping, and thereafter the river would be virtually dry during the months of November to June. Several years would be required to obtain the full storage potential. Each year the water table at the beginning of the monsoon season would be pumped deeper than the year before, until an equilibrium would ultimately be reached.

Pumping out Groundwater during Low Flow Season

For a rough estimate we may assume that along 3200 km of the system of larger tributaries of the Ganges (about a quarter of the total length) large well fields could be constructed which would produce storage space by pumping out the groundwater during the low flow season. With well fields 6 km wide on either side of the river, the area covered would be 3.8×10^6 ha. If we assume that the well field capacity is 2.25 m^3/sec per kilometer (that is, 1.12 m^3/sec on each side of the river per kilometer of length) and the storage coefficient of the aquifer is 0.25, then the water table will be lowered, on the average, about 12 m at the end of 8 months of continuous pumping. All the wells need not be of the same capacity. It is necessary only to design the well spacings and discharges in such a way that we pump out a trough of 12 m below the river bed. The method used for finding the depression of the water table is given below.

The drawdown due to pumping in an aquifer is given by

$$s = \frac{Q}{4\pi T} \int_{\frac{r^2 S}{4Tt}}^{\infty} \frac{e^{-u}}{u}\, du \qquad (1)$$

where the drawdown $s = h_1 - h$ (m), h_1 is the initial saturated thickness of the aquifer (m), h is the height of the water table during pumping (m), Q is discharge (m^3/day), T is the coefficient of transmissibility (m^2/day), S is the storage coefficient (dimensionless), t is time since pumping started (days), and r is the distance from the pumping well (m).

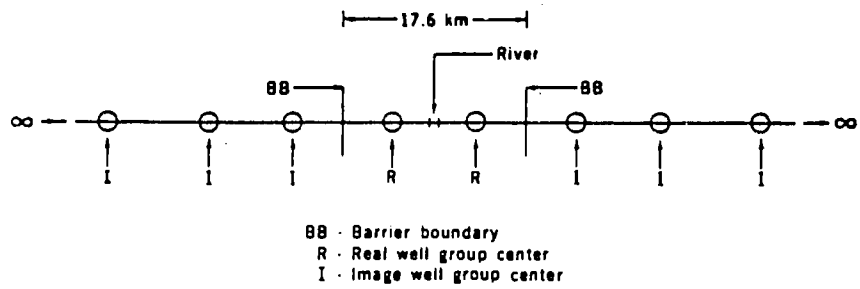

Fig. 1. Location of real and image well groups.

Equation 1 holds strictly only for a confined aquifer which is isotropic and homogenous. However, it can be used for an unconfined water table aquifer (as in the present case) provided drawdown is small compared with the original saturated thickness of the aquifer. In the Ganges Plain the aquifers are quite thick, and the drawdown of the water table will be small compared with the initial saturated thickness of the aquifer; consequently, we can apply Eq. 1. There are other assumptions involved in the derivation of Eq. 1. Revelle and Herman (*3*) showed that, although these assumptions are not strictly valid in the present case, the equation can still be used to give a fairly good solution.

Equation 1 is the solution of the differential equation

$$\frac{\partial^2 h}{\partial r^2} + \frac{1}{r}\frac{\partial h}{\partial r} = \frac{S}{T}\frac{\partial h}{\partial t} \qquad (2)$$

subject to certain simple boundary conditions. Since Eq. 2 is linear, the superposition principle can be used to find the solution when more than one well is being pumped in the aquifer. Equation 1 is obtained on the assumption that the aquifer is areally infinite. If we have boundaries then we must use the method of images.

In the present calculation we have assumed that there is a natural groundwater divide at a distance of 8 km on either side of the river. This is approximately true for many of the tributaries that feed the main tributaries of the Ganges. The natural groundwater divide acts as an impervious barrier. The presence of the river itself can be ignored in the computations, since during the dry season the quantity of flow in many Ganges tributaries will be small compared with the quantity of pumping. Grouping the wells in pumping centers, we will have the real and image wells shown in Fig. 1. Because of the assumed existence of an impervious boundary on either side of the river, there will be an infinite number of images. However, only a few need to be considered, since the effect of image wells very far off will be small near the river.

Equation 1 is applied repeatedly for all the real and image wells, and we obtain a lowering of the water table, on the average, of about 12 m at the real wells.

Table 2. Possible river reaches for underground storage of monsoon flows (assuming storage of 1800 ha-m per kilometer of river). Estimated monsoon and dry-season flows are based on U.N. data (*2*).

River	Length of well fields (km)	Monsoon flow ($\times 10^6$ ha-m)		Dry-season flow ($\times 10^6$ ha-m)	Ratio of dry-season to stored flow (%)
		Stored underground	Remaining in river		
1) Ganga to Yamuna	720	1.3	0.1	0.3	23
2) Ramganga	560	1.0	0.1	0.2	20
3) Yamuna system	1440	2.6	0.3	0.7	27
4) Gumti and Sai	610	1.1	0.1	0.3	27
5) Gagra, Sarda, and Rapti	1280	2.3	3.2	1.2	52
6) Son	640	1.2	1.0	0.5	42
7) Buhri Gandak and Baghmati	720	1.3	3.2	1.0	77
8) Below the Kosi, including Mahananda	400	0.7	1.1	0.4	57
Totals	6370	11.5	9.1	4.6	42
Sum of 1 to 4	3330	6.0	0.6	1.5	25
Sum of 5 to 8	3040	5.5	8.5	3.1	56

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Recharge of Groundwater Mound by Monsoon Flow

When pumping stops at the end of the dry season there is some flow into the trough from the sides. It is therefore assumed that we have a net trough with an average depth of 10 m to be partly filled by monsoon flow in the river.

The growth of the groundwater mound resulting from infiltration of the monsoon flow in the river is computed by using the following equations given by Hantush (*7*)

$$h^2 = h_1^2 + \frac{W}{K}\frac{T}{S}t\left\{2 - 4i^2\,Erfc\left[\frac{L-x}{\left(4\frac{T}{S}t\right)^{\frac{1}{2}}}\right] - 4i^2\,Erfc\left[\frac{L+x}{\left(4\frac{T}{S}t\right)^{\frac{1}{2}}}\right]\right\} \quad \text{for } x < L \qquad (3)$$

$$h^2 = h_1^2 + \frac{W}{K}\frac{T}{S}t\left\{4i^2\,Erfc\left[\frac{x-L}{\left(4\frac{T}{S}t\right)^{\frac{1}{2}}}\right] - 4i^2\,Erfc\left[\frac{L+x}{\left(4\frac{T}{S}t\right)^{\frac{1}{2}}}\right]\right\} \quad \text{for } x > L \qquad (4)$$

where the symbols other than the ones already used are: W, recharge rate through the bed of the river (m/day); K, coefficient of permeability in the aquifer (m/day); t, time during which recharge takes place (days); L, half-width of river (m); x, distance from center of river (m); and

$$Erf(x) = \frac{2}{\pi^{\frac{1}{2}}}\int_0^x e^{-\zeta^2}d\zeta$$

$$Erfc(x) = 1 - Erf(x)$$

$$4i^2\,Erfc(x) = Erfc(x) - 2x\,iErfc(x)$$

Since Eqs. 3 and 4 are implicit, a trial and error procedure or a graphical method has to be adopted for solution. For example, assume $t = 15$ days. Then, using $T = 4650$ m²/day, $L = 150$ m, $W = 0.61$ m/day, $K = 15.2$ m/day, $S = 0.25$, $h_1 = 300$ m, and $t = 15$ days, we get $(4Tt/S)^{1/2} = 1055$ m and $L/(4Tt/S)^{1/2} = 0.144$. From Eq. 3 we find

$$h^2 = (300)^2 + \left(\frac{0.61}{15.2} \times \frac{4650}{0.25} \times 15\right)(0.56) = 96{,}270 \text{ m}^2$$

Therefore

$$h = 310 \text{ m}$$
$$h - h_1 = 10 \text{ m}$$

Thus the time for the water to rise 10 m at the center of the recharging strip is 15 days.

The height of the groundwater at a distance of 600 m from the center of the river can be computed as follows

$$\frac{x-L}{\left(4\frac{T}{S}t\right)^{\frac{1}{2}}} = \frac{450}{1055} = 0.43$$

$$\frac{x+L}{\left(4\frac{T}{S}t\right)^{\frac{1}{2}}} = \frac{750}{1055} = 0.72$$

Using Eq. 4 we obtain

$$h^2 = (300)^2 + \left(\frac{0.61}{15.2} \times \frac{4650}{0.25} \times 15\right)(0.35 - 0.14) = 92{,}350 \text{ m}^2$$

Therefore

$$h = 303.5 \text{ m}$$
$$h - h_1 = 3.5 \text{ m}$$

Similarly at 1500 m, we obtain

$$h^2 = (300)^2 + \left(\frac{0.61}{1512} \times \frac{4650}{0.25} \times 15\right)(0.016 - 0.005) = 90{,}123 \text{ m}^2$$

$$h = 300.2 \text{ m}$$
$$h - h_1 = 0.2 \text{ m}$$

Thus, assuming that the rate of recharge is 0.61 m/day, which is a rather conservative figure, the height of the water mound at the end of 15 days will be 3.5 m at a distance of 600 m and 0.2 m at a distance of 1500 m. From this we can compute the quantity of monsoon water abstracted as 1×10^6 ha-m. After 15 days there will still be some recharge, because some of the bank flow from the river will continue to fill the trough. Thus, during the first year of operation somewhat more than 1×10^6 ha-m will be extracted from the monsoon flow. When this is spread over the groundwater basin 17.5 km wide, it will raise the water table by 0.75 m. To this we may add a rise of the water table by 0.6 m caused by 15 cm of net rainfall infiltrating to the water table. Thus, at the beginning of the second year of operation the water table will be about 8.6 m below the level at the beginning of the first year.

During the second year of operation the water table will be lowered by 10 m to a depth of about 18.6 m before the monsoon flow begins. The time taken to raise the water table 18.6 m at the center of the river bed during the monsoon comes to 33 days. At this time the height of the groundwater mound will be 7.5 m at a distance of 600 m and 1.5 m at a distance of 1500 m. The total quantity of monsoon water extracted will be about 2×10^6 ha-m, again ignoring the contribution from bank flow. This will raise the water table by about 1.5 m. Adding about 0.6 m due to infiltration of rainfall, the depth of the water table at the beginning of the dry season in the following year will be 16.5 m below the initial level.

During the third year of operation this will again be lowered by 10 m, leaving the water table at a depth of about 26.5 m at the beginning of the monsoon. The time taken for the water table under the river to rise 26.5 m is about 70 days. At this time the height of the groundwater mound will be 15 m at a distance of 600 m, 5 m at a distance of 1500 m, and 0 m at a distance of 3000 m. Thus, the amount of water extracted from the monsoon flow, ignoring the contribution from bank flow, will be about 6×10^6 ha-m. At the end of the monsoon the water table will be at an average depth of about 22 m over the cross section of 17.5 km.

By similar computation, we can show that during the fourth year of operation the depth of the water table at the end of the pumping season will be 32 m, and in the 120 days of the monsoon season we will extract from the monsoon about 9×10^6 ha-m. The depth of the water table at the end of the monsoon will be about 25 m below the initial level 4 years earlier.

From the following year onward, the water table will be stabilized at these levels by pumping out a quantity equal to consumptive use plus surface drainage plus return infiltration to the groundwater table.

Figure 2 shows the growth of the groundwater mound under uniform recharge from the river for the stated values of the parameters. Because different scales have been used in the horizontal and vertical directions, the slope of the water table appears to be steep. Actually its profile will be very flat. For instance, at the end of the first monsoon period the slope will be approximately 1 to 170; at the end of the fourth monsoon period it will be approximately 1 to 140. We can therefore use the bank storage equations given by Cooper and Rorabaugh (*8*) for a horizontal water table, as shown in the next section.

With any particular set of assumed parameters, equilibrium will be reached in the number of years required to lower the water table to a depth such that 120 days (the length of the monsoon season) will be required for the

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infiltration mound to reach the bed of the river. For example, assuming a storage coefficient of 0.15, a transmissibility of 2800 m^2/day, and a pumping rate of 1.35 m^3 sec^{-1} km^{-1}, an equilibrium depth of 35 m at the end of the monsoon season will be reached in about 12 years. From that time onward, 6×10^6 ha-m will be stored each year.

During the monsoon season the rivers in northern India always carry some water, with flood peaks occurring after every heavy storm. Thus, even if the duration of the flood wave is short, say 6 to 12 hours in the smaller streams (longer in bigger tributaries)—recharge will continue under the lesser flow that prevails before and after its passage. Hence we can assume that about 120 days is always available for recharge during the monsoon season.

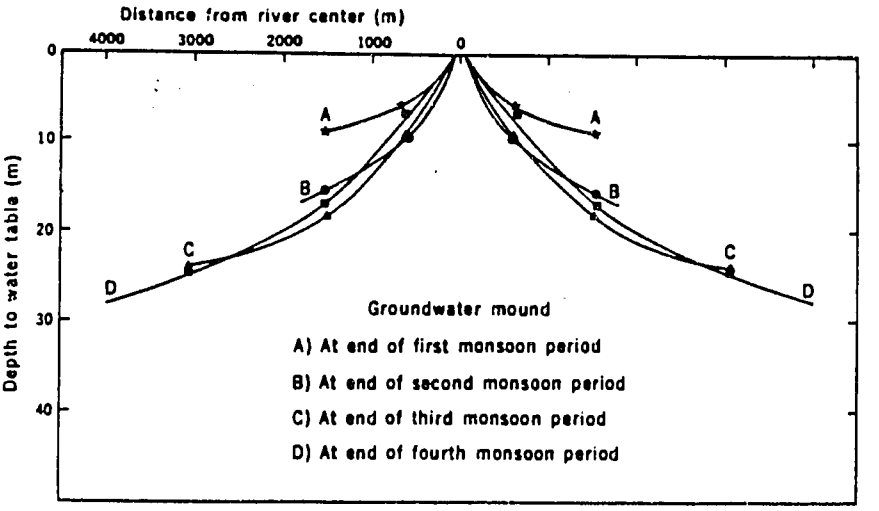

Fig. 2. Growth of groundwater mound under uniform recharge from river.

Advantages of Aquifer Storage

Flood amelioration. During the flood wave there will be much more bank storage than there is now along the tributaries where the water table has been lowered by pumping. This will supplement the aquifer storage described above in reducing downstream flooding. The amount of bank storage can be computed from the equations of Cooper and Rorabaugh (*8*).

Assuming a flood duration of 3 days, a flood crest of 3 m, aquifer transmissibility of 4650 m^2/day, and a storage coefficient of 0.25, the amount of bank storage 2 days after the beginning of the flood will be 2.3×10^5 m^3/km. This temporary bank storage is 50 percent of the water entering the aquifer during the same 2-day period; 75 percent of the bank storage will return to the river during the following 7 days.

Use of stored monsoon waters in irrigation. The area to be irrigated with the pumped waters would be larger than that of the well fields. Assuming 6×10^6 ha-m of storage from the monsoon flow, and adding the rainfall infiltration of 0.15 m, the gross irrigated area would be 17.5 to 19 m-ha. Here we assume that an amount of water equal to 10 percent of consumptive use by evapotranspiration is allowed for drainage to maintain a salt balance, or alternatively the original dry season flow of the river is returned downstream of the well fields in order to maintain the low flow. If the irrigated areas, including the zone of intense pumping, were located in strips along both sides of the rivers used in the scheme, the average width on each side of the rivers would be roughly 27 to 30 km.

Allowing for 20 percent return infiltration of the pumped water, the total pumping from the irrigated area during the dry season is about 10.5 $\times 10^6$ ha-m, requiring a total well capacity of around 5000 m^3/sec. If the well fields are 6 km wide on either side of the river, more than half the net volume pumped would need to be transported to the outer 21- to 24-km strip in surface conveyance channels. Since unlined channels inevitably leak into the ground a considerable fraction of the water they carry, this surface distribution system could, with proper management, also be used as a groundwater storage mechanism. For example, if the channels extended to the river, they could be used as inundation canals for irrigation during the monsoon season, and 30 to 50 percent of the water carried in them would be expected to seep downward to the aquifer.

Possible Tributaries for Monsoon Storage

Table 2 shows possible river reaches along which the underground storage scheme for the monsoon waters might be used, and Table 1 shows a possible future water budget for the Ganges Plain. It will be seen that in the western tributaries the initial dry-season flow would be about 25 percent of the water coming from the rivers into the aquifer. A portion of the pumped water would be needed for water supply and waste disposal for cities and towns along these rivers; return flows from irrigation could also be used for waste disposal. In either case, conveyance channels or pipes for the pumped water would be required. In the central and eastern plain, the dry-season flow probably comes largely from the Himalayas and equals 42 to 77 percent of the quantity of stored monsoon water. For economy in pumping and ease in maintaining the low flow water supplies for cities and towns, it would probably be desirable to construct diversion barrages upstream of the well fields and lined channels to carry the diverted water downstream of these fields.

Costs and Benefits of the Storage Scheme

Power requirements for pumping stored monsoon waters. Assuming an average pumping lift of 30 m, the net electrical energy required to pump 10.5 $\times 10^6$ ha-m would be 8.75×10^9 kilowatt-hours. With an overall efficiency of 67 percent, including transmission losses, the energy required at the generating plant would be 13×10^9 kwh, corresponding to an installed power capacity of 3000 megawatts at 50 percent load factor.

The electrical power requirement could be supplied by mine-mouth electric generating plants in the Raniganj-Jharia coal fields in Bihar, or by utilizing a small fraction (possibly less than 15 percent) of the enormous potential hydroelectric capacity of Nepal. (It is sometimes said that the force of gravity,

expressed in falling water, is Nepal's principal natural resource.)

All the methods we have described for underground storage of monsoon waters would involve use of electric or diesel power for pumping. Because of the greater depth of pumping, the energy requirements for the river storage scheme would be larger than for other methods. But the ratio of benefits to costs would still be high.

Annual costs and benefits of the storage scheme. At $0.02 per kilowatt-hour, the annual power cost would be $260 million, or about $14.50 per gross irrigated hectare. At $0.005 per kilowatt-hour, the power cost would be $3.65 per gross irrigated hectare.

Construction costs of tube wells per unit of capacity diminish with increasing well capacity. Compared with larger wells, the maximum cost should be for wells pumping 0.03 m^3/sec. Assuming that the cost is $10,000 per well, the total cost for 170,000 wells would be $1.7 billion. Amortized over 10 years at 8 percent, the annual costs of well construction would be roughly $14.00 per gross irrigated hectare. To these fuel and capital costs should be added the cost of land for the tube wells and the drainage and conveyance channels, the cost of constructing these channels, and the labor costs for maintenance and operation of the system. With our present information we are unable to estimate these costs, but we believe they should be less than $15 per year per gross irrigated hectare.

The total annual costs would thus be about $40 to $45 per gross irrigated hectare. With adequate water management and proper use of fertilizers and other inputs, it would be possible to obtain high productivity from high-yielding crop varieties on the irrigated fields, in contrast to the present yields from traditional varieties, which must be used on unirrigated lands. The gross value of cereal crops would be of the order of $500 per hectare, ten times the annual costs of irrigation water supplies.

Of equal importance would be the increased food production from the newly irrigated lands. For the entire Ganges Plain, the storage of monsoon waters along tributaries by the pumping scheme we have proposed would provide a basis for an increase in production of 55×10^6 metric tons per year. All storage methods combined, together with increased kharif irrigation from canals, would give more than 110×10^6 tons above present production, enough by itself to provide a greatly improved diet for 400 million people.

In Table 1 we estimate that 6×10^6 ha-m would be used for irrigation during the kharif season of monsoon rainfall and high river flows. The necessity for irrigation in this season is due both to the large variation from year to year in total monsoon rainfall and to the intraseasonal irregularity of the rainfall. In many areas, water supplies for monsoon irrigation could be obtained by construction of barrages across Ganges tributaries, which will divert waters into systems of canals, distributaries, and water courses. From 35 to 50 percent of this water will seep into the ground and can be used for well irrigation during the dry season. Thus, the possibilities for total underground storage are much larger than our estimates of the storage that can be obtained by pumping out the aquifers along tributaries. The total potential irrigation in the Ganges Plain may be limited by the area of irrigable land rather than the water supply.

Need for Further Investigation

The choice between systems for storage of underground water will vary from region to region, and possibly with the stage of development of the integrated system of surface and groundwater irrigation. Further detailed field investigation and systematic analysis are required to determine the choice and sequence of investments for irrigation. Among the factors which should be considered are: the effects of sediment transportation and deposition, which might reduce infiltration rates from the rivers, the possible hazards of subsidence resulting from lowering the water table, and possible ecological effects. Special attention should be paid to design and construction of irrigation projects that are compatible with the long-range objectives of storing monsoon waters and maintaining the present volume of flow during the dry season. Projects that are incompatible with these objectives should not be initiated.

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   The average amount of water evaporating from the water table is probably between 2 and 3 cm. A reduction of 2 cm over an area of 40×10^6 ha might be obtained if the average depth to the water table were lowered by a few meters. This should not seriously interfere with the seepage of groundwaters into the rivers, which is the source of much of the river flows during the dry season. We estimate that construction of a sufficient number of low bunds at right angles to the flow lines in uncultivated areas might increase rainfall infiltration by 10 percent or 0.7×10^6 ha-m.

Dasheen leaf [Courtesy U.S. Department of Agriculture, Washington, D.C.] →

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Land Use for Agricultural Production: Agricultural Land Use and Soil Erosion

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The purpose of this paper is to describe briefly the present agricultural land use pattern in the U.S. and to indicate some of the more important agronomic factors influencing agricultural land use changes and potential soil erosion.

Land Use in the United States

The land surface of the United States is a semi-fixed quantity standing at 2,313 million acres. About 42 million acres are covered by water, bringing the total land surface to about 2,271 million acres [1]. In 1969 about 80 per cent of the total land area was used for direct agricultural production, including forestry and grazing. About half of the other 20 per cent was used for urban development, transportation, public installations, wildlife refuges, and recreation facilities. The remainder was desert, swamp, tundra, or other land of limited use [2, 3]. During the period 1959 through 1969, approximately 2.2 million acres of rural land were shifted each year to non-farm uses. These uses included urban development (730,000 acres), airports and highways (130,000 acres), reservoirs and flood control (300,000 acres), recreation and wilderness areas, parks and wildlife refuges (1,000,000 acres) (excluding Alaska) [2, 3].

In 1958 and again in 1967, the Soil Conservation Service and cooperating agencies made a national inventory of the soil and water conservation needs [3]. In the 1958 inventory, a soil survey was made of selected sample areas of all rural land, excluding non-cropped federal land. These data were expanded, using appropriate statistical procedures, to estimate the acreage of different land uses in each county. All land uses were estimated by field inspection of sample areas. This was called a Conservation Needs Inventory (CNI). Of the 1,438 million acres in the 1967 CNI in the United States, approximately 30 per cent was estimated to be cropland, 34 per cent permanent grassland, and 32 percent forest land. Other land uses, including farmsteads, farm roads, and miscellaneous uses, amounted to 4 per cent.

Soil mapping units mapped in the soil survey were classified and grouped into eight general land capability classes that were defined on the basis of the degree of soil limitation for growing field crops. The capability grouping reflects potentialities and limitations for sustained production of common field crops without specialized site conditioning. Class I land is suitable for the continuous cultivation of most agricultural crops without special water and erosion control measures. Class II and Class III land are suitable for regular and fairly intensive cultivation of most field crops if conservation treatments are applied. These practices include water conservation and erosion control measures and, in addition, ade-

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quate fertilization. Class IV land is marginal for growing most field crops. Soil mapping units grouped into Land Classes V, VI, VII, and VIII generally are not suitable for growing most field crops, but are suitable for other, less intensive uses, such as permanent pasture, woodland, and some horticultural crops [4].

The acreage of land by individual land classes is shown in Table 1.

TABLE 1.

Conservation Needs Inventory Acreage in Land Use Capability Classes, U.S. 1967

Capability Class	Acreage Millions of Acres		Percent of Inventory Area	
I	47	631	3	44
II	287		20	
III	297		21	
IV	180		13	
V	32	627	2	41
VI	278		19	
VII	287		20	
VIII	30		2	

The land (631 million acres) suitable for cultivation (land Classes I, II, III) is approximately equal to the amount of land unsuited to cultivation, (Land Classes V through VIII).

The 1967 Conservation Needs Inventory determined the major types of land use and the acreage in each of the land classes. Cropland, pasture and range land, forest land and other land use acreage by land class groups is shown in Table 2 [3].

Fifty-eight per cent of the land suitable for crop land (Classes I, II, III) was used as cropland. Thirty-eight per cent was used for pasture and woodland. This potential cropland constitutes a reserve that could have been converted to crop production on demand. Soil erosion losses would be expected to be much less on most of the class I, II, and III land used for pasture and woodland than if they were used for tilled crop land. Twenty-five million acres of the land in classes V through VII were unfortunately in cropland. This land is poorly suited to crop production. On much of this land, erosion control practices probably are not feasible. Some shifting of this land to other uses has occurred. In 1949 the estimated land used as cropland in the U.S. included 39 million acres of land in Classes V through VIII. Some of this land has been shifted to pasture and trees by 1958, thus decreasing its erosion potential. Twenty-eight per cent of the Class IV land was being used for cropland in 1967. There were 47 million acres of Class I land in the U.S. in 1967; only

TABLE 2.

Land Use by Land Capability Class in the 1967 Conservation Needs Inventory

Land Classes	Millions of acres	Per cent of total acreage within class groups
I, II, III		
Land Use		
Cropland	365	58
Pasture & Range	117	18
Forest	126	20
Miscellaneous Use	23	4
Total	631	
Land Use		
Cropland	50	28
Pasture or Forest and Miscellaneous	130	72
Total	180	
V, VI, VII, VIII		
Land Use		
Cropland	25	4
Pasture or Forest	577	92
Other land uses	25	4
Total	627	

thirty-six million acres, or 77 per cent, were being used for cropland. Eleven million acres of the Class I land suitable for continuous row crops were used for pasture and woodland and other uses [3].

These data appear to indicate that land users generally have done a fair to good job of matching the use of the land to the land use capability class of the soils. However, since 11 million acres of the Class I land, and 243 million acres of Class II and III land were used principally for pasture and forest in 1967, one might conclude that there was suboptimal use of much of the land with respect to its physical capability. The fact that 25 million acres of the Class V through VIII land were used as cropland also indicates that much of the land was not matched to its most suitable use in 1967.

There are many possible reasons that explain partially the matching or mis-matching of crops to the conservation and productive potential of the land. Some of the most important factors that have influenced land use are the physical and chemical characteristics of the soils and the configuration of the landscapes. Although social, institutional, and economic factors also have influenced land use, they will not be considered within the scope of this discussion.

Soils and landscape features have played a dominant role in influencing the distribution of otherwise climatically adapted crops. Three physical characteristics of land influence its use for crop production; 1) the soils, 2) their pattern of distribution on the landscape, and 3) the features of the landscape.

Some of the soils in land use capability classes II and III, even though suitable for cropland, have relatively low and highly variable crop yields due to a variety of factors. They may be excessively wet, as is the case of the soils included in sub-classes IIs, IIIs, IIc, and IIIc. It may or may not become economically feasible in the future to modify these conditions by drainage or irrigation. Soils in sub-classes IIe, IIIe, and IVe have sloping topography and are subject to excessive erosion unless adequately protected by erosion control practices. The economic feasibility of such practices is strongly dependent on the economic value of the crops to be grown and societal incentives.

Since most of the Class IV, V, VI, VII and VIII soils are poorly suited to tilled crops, land users have tended to shift this land to pasture and woodland. The small pockets of Class I, II, or III soils that are intimately associated with higher classification soils were also shifted to pasture and woodland because those areas were too small to be farmed with large farm machinery.

Where relatively large acreages of Class I, II, or III land are found in natural bodies along narrow stream valleys, farm property lines dissect these areas into small irregularly shaped units that are ill-suited to mechanized farming. Also some potential crop land (Class I-III) that is found along streams may be flooded frequently and hence it would be too risky for use with tilled crops.

Tabor [5] found in a study of individual tracts of land in 3 soil associations in Maury County, Tennessee, that many of the highly productive soil mapping units suitable for intensive row cropping were small in size, irregularly shaped and occurred in a distribution pattern that made it difficult to combine them with other similar soil mapping units into large fields for efficient use of large farm machinery. Using a 2-acre minimum field size, cropping systems to keep the soil loss within tolerance limits, and certain field shape restrictions, he found that much of the cropland had to be shifted to pasture or idle land with greatly reduced net income. The average net income for the 3 soil associations after imposing these restrictions was 52 per cent less than the net income without these restrictions.

Oschwald [6] studied the effect of soil mapping unit distribution patterns on crop sequence suitability in Iowa. He found that Sharpsburg, 2 to 5 per cent slopes, was suitable for continuous corn with suitable erosion and water control practices when considered alone, but only 40 per cent could be in continuous corn if the soil pattern in which it occurred were considered. In another soil pattern, Colo-Gravity, 2 to 5 per cent slopes, the combined effect of stream dissection and of occurrence with predominately more sloping soils resulted in less than 3 per cent continuous corn suitability for this association.

Smith [7] using CNI data (1958) found that approximately 6 million acres of Class I-III land in the Tennessee Valley were idle, in pasture or in woodland. This represented over 50% of the Class I-III land in the Tennessee Valley. Boxley and Blass [8] associated this extensive land use to the occurrence of part-time farms. For example, farmers shifted their land to pastures for a cow-calf system of beef cattle farming which was compatible with their off-farm work.

Small areas of productive soils in Land Classes I and II are well suited to some high labor-intensive crops such as burley tobacco. Usually small acreages of such crops per farm utilize these small areas of productive land very efficiently. However, shifts of large acreage to this type of row crop culture in the future is unlikely.

These soil and landscape relationships have many counterparts in many other regions of the U.S. Hence, they appear to be a major factor in determining the use of land for tilled crop production where large fields are required for the efficient use of mechanized equipment. Much of the eastern U.S., especially the Appalachian region, the Delta states and the Piedmont regions of the Southeast, and to a much lesser degree the corn belt, and the Plains states, have a soil distribution pattern and landscape features that make many areas poorly adapted to the use of the large mechanized planting and harvesting equipment. A land use pattern where large acreages of Land Classes II and III are used for pasture and woodland with appropriate management has the potential for greater reductions of soil erosion losses than if they were used for cropland.

The soil distribution pattern of the U.S. has been greatly influenced by the natural erosion and deposition which have influenced the present land use pattern. The young alluvial soils and loess and glacial till-derived soils which comprise much of our productive cropland are the result of natural processes of erosion and sedimentation. The slow evolutionary geologic erosion and sedimentation process has not

been a despoiler of the environment; it has played quite the opposite role. However, when the rate of erosion and sedimentation processes are greatly accelerated, erosion of upland and terrace soils exposes clayey horizons, fragipans, or other undesirable subsurface horizons that result in lower moisture supplying capacity. Where yields of tilled crops are greatly reduced, land users have shifted much of this land to permanent pasture or woodland, and soil erosion has been arrested.

Cropping Systems in Relation to Soil Resources

Of the total agricultural land in the U.S., the cropland harvested has a greater potential for soil erosion than pasture or woodland since during a portion of the year, the land usually is not protected with actively-growing vegetation. Numerous measurements of soil erosion from field plots leave no doubt that cultivated fields can be a major contributor to the erosion-sediment problem.

Fully 90 per cent of the total crop acreage harvested is accounted for by corn, grain sorghum, wheat, oats, barley, cotton, soybeans, and hay crops. From 1930 to 1970 the harvested cropland acreage in the continental U.S. has been steadily declining. The acreage of crop land harvested declined from approximately 360 million acres in 1930 to 285 million in 1970, about 21 per cent [9].

Significant regional changes in harvested cropland have occurred in the last two decades. In some regions acreage of harvested crops has declined, while in others it has increased. From 1940 to 1965, land in harvested crops declined 54 per cent in the Northeastern states, 33 percent in the Appalachian region, and 26 per cent in the Delta states. During the same period land in harvested crop acreage increased 4 per cent in the Corn Belt, 1 per cent in the northern Plains states, 29 per cent in the Mountain states and 8 per cent in the Pacific states [10].

The eastern U.S. has experienced a greater decline in harvested cropland than any other region of the country. Much of this is due to the soil patterns and landscape features which are undesirable for mechanized farming and effective erosion control. The decline is also partly due to the past accelerated soil erosion in the area. Much of this area, which formerly was in row crops, is moderately to severely-eroded and produces low and often uneconomical yields of tilled crops. It has been planted to adapted perennial grasses and trees and accelerated erosion has been arrested. The rapid urbanization of this region also has occupied some of the cropland. Much of the increase in harvested crop land acreage in the Mountain and Pacific states has been on nearly level irrigated land with a low erosion potential. [9].

The present regional land use pattern in the U.S. for the major harvested crops is indicative of the appropriate matching of these crops and the accompanying technology to the soils, climate, and water resources of the different regions. Within the more humid regions of the U.S. the climatic patterns, the soils, and the landscape features are dominant factors influencing crop distribution and land use. In the arid regions, availability of adequate quality and amounts of irrigation water is an additional dominant factor.

Most of the acreage of corn is in the Corn Belt states, where it is well suited. Soybeans, traditionally a Corn Belt crop, have expanded into the southeastern states particularly in the Mississippi Delta. Grain sorghum production is concentrated in the southern Plains states, where in recent decades it has replaced some of the corn acreage. Some of the acreage of grain sorghum has entered the western Corn Belt. To a lesser extent, grain sorghum is grown in the irrigated regions of the southwest. Cotton acreage has declined in the Piedmont areas of the southeast and has shifted to the more gently sloping land of the Coastal Plain and Delta regions. It has also increased in the irrigated areas of the southern Plains states, the Southwest and California. [9].

Small grain acreage is concentrated in the Plains states. Cotton production, which requires a long growing season, is restricted to the southern and southwestern U.S. Soybeans, grain sorghum, corn, small grain and many hay crops, using locally adapted cultivars, have a rather wide range of adaptation. These crops generally are being produced in regions and on soils within regions where they have the greatest competitive advantage.

As acreage used for crops has decreased and harvested crop acreage has shifted among and within regions, crop yields have increased dramatically. From 1950 to 1971, the crop production per acre increased about 60 per cent [2]. With the increased crop yields per acre, the area needed to produce a given crop production volume has decreased dramatically; this is perhaps one of the most significant factors influencing land use in the last three decades.

Barrons [9] has computed the acreage that would be required to produce the total production of recent years (1968-70) at the yield level existing before present technology and methods of crop production came into full play (1938-40). The U.S. acreage of 17 major harvested crops, saved annually for alternative uses during 1968-70 as a result of increase in yield of these crops since 1938-40, is

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approximately 290 million acres. This is approximately equal to the total 1970 acreage of cropland in the continental U.S., an area equal to all the land in the U.S. east of the Mississippi River and south of the Ohio River. If we were now obtaining the crop yields that prevailed in the late 1930's, this greater required acreage would be on the more erodible rolling topography. Thus by increasing the yield per acre, some of the cropland that would be subjected to soil erosion can be shifted to permanent pasture and woodland, where the potential for soil erosion is much less.

The phenomenal increase in crop yields is due to no single cause, but to the development and application of a systems approach to land management, where multiple limiting factors are considered simultaneously. Adding one or more production factors when others are limiting can be counterproductive. Crop response to one or more factors of production is usually dependent on the level of other factors. The sum of the independent yield effects of two or more added deficient factors of production is often times less than the yield effects when added together. This is generally called the principle of interaction. The use and application of this systems approach especially in the use of increased and more efficient amounts of management inputs for crop production account for the dramatic upsurge in crop yields in the past three decades.

Even though the systems approach to land management has not been applied universally to all our farm land, enough has been applied to increase crop yields. The following production technology has been incorporated in land management systems and applied widely to crop production throughout this country.

Crops have not only been matched to the major soil and climatic regions but to much of the land on individual farms within a given soil and climatic region. Crops have been matched to the soils and landscape features for which they are best suited using modern mechanization and other technology. In the more humid regions of the U.S., tilled crops usually have been allocated to the well-drained and moderately well-drained soils with high moisture-supplying capacity and with nearly level or gently sloping topography, for high and more certain yield and permissible soil erosion loss. Small grain and other cool-season crops are usually allocated to the more droughty soils and sloping topography, since moisture is rarely a limiting factor during their growing season. Furthermore, since they are close-seeded crops the erosion hazard on slopes is less serious than with row crops. Pasture and hay crops also are adapted to and compatible with a wide range of soil drainage and more sloping topography, although these crops are usually less profitable than tilled crops on the more productive soils. They often are allocated to poorly or somewhat poorly drained soils, or to droughty soils on rolling to steep topography. Being close-seeded crops, and usually perennial, the erosion hazard on rolling and steep topography is much less serious than with row crops or small grains. Cropping systems also have been matched not only to the land but to the livestock system and to other resources, including the management ability of the farmer.

Appropriate matching of crops to the land on individual farms and the selection of appropriate water and erosion control measures have been greatly aided in the past decade by the widespread availability and use of detailed soil survey maps, and by the development and use of the Universal Soil Loss Prediction Equation. As of June, 1972, the Soil Conservation Service and cooperating agencies have reported detailed soil survey mapping on a total of 774 million acres, and 41 million acres of reconnaissance soil surveys. In addition, exploratory soil survey mapping has been completed on 274 million acres in Alaska. Detailed soil maps and accompanying soils information are widely accepted and used by professional farm managers and agricultural workers for farm and ranch planning [11].

The Universal Soil Loss Prediction Equation is being used for planning cropping systems and water and erosion control measures in the 36 states east of the continental divide. There is also some use of the soil loss equation in the states west of the continental divide, particularly Utah and Idaho. The states of Montana, Wyoming, Colorado, and New Mexico are using the equation in the portion of the states east of the divide. The USLPE has been well accepted by soil conservationists and some farmers in the states where it is being used. The best example of impact of the soil-loss equation is the new Iowa Soil Conservation Act-House File 73. The soil-loss equation is used to estimate the soil loss on areas where soil erosion has been declared a nuisance. Thus it has become a valuable tool for implementation of the law [12].

Few farmers in the U.S. are following a rigid crop rotation. Most farms have diverse soil and topographic patterns. If rotation were practiced on all the land, some row crops would be grown on soils for which they are not well-suited for either production or control of soil erosion. By concentrating the row crops on gently sloping or nearly level productive lands and continuously cropping them,

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higher yields and less soil erosion can result on the farm as a whole.

In the Midwest, on nearly level and gently sloping topography, corn is seldom rotated. Before World War II a 2-year rotation of corn-oats-clover was used and an average yield of about 38 bushels of corn per acre was obtained. Instead of planting 33 of each 100 acres in corn and obtaining a total yield of 1250 bushels, now the farmer plants the whole 100 acres in corn and harvests 10,000. This shift to more continuous cropping on the potentially more productive soils occurring on less gently sloping topography has occurred also with other row crops in other regions of the U.S.

Multiple cropping is defined as the harvesting of one or more crops from the same land area during a given period of time, usually one year. Increased total yield per unit area can be obtained from harvesting more than one crop during a growing period. Multiple cropping is a practice widely used with vegetable crops, and it is gaining acceptance with other crops. With adequate length of growing season corn silage can be double-cropped with small grains for forage. Soybeans are double-cropped with small grains. These practices have not only provided a method for increasing the total yield per acre, but they may decrease erosion because live vegetation is on the land a greater portion of the year.

In the past three decades strip-cropping, terraces, contour farming, minimum tillage systems, and many other soil erosion control measures have been adopted and used on millions of acres of cropland. These measures have not only aided land users in reducing soil erosion but also have contributed to maintaining soil productivity and reduced off-site sediment damage. However, implementation of erosion control measures on cropland is far from being completed [3]. For example, only 36 per cent of the cropland, as reported in the Conservation Needs Inventory, has been adequately treated with soil and water conservation practices and measures to hold soil losses to an acceptable level.

From 1950 to 1970, commercial fertilizer use more than doubled, from 18.0 to 39.2 million tons [13]. During this period, fertilizer efficiency has also increased with increasing use of soil tests, and the amount of fertilizer applied has been in a more balanced relationship to the available levels in the soil and to the specific requirements of a crop and its predicted response. Farmers also have adjusted the amounts added according to the available moisture supplying capacity of the soil, or in case of irrigated soils, they have adjusted the amounts of fertilizer in relation to the supply of irrigation water. Much land formerly planted to forage legumes in order to supply nitrogen for corn and other cultivated crops is no longer used in this way since most of the nitrogen is obtained from commercial N.

Increased use of fertilizer, along with other inputs, has greatly increased the yield and vigor of vegetative growth of crops and hence has increased protective capability of the crop against soil erosion loss. Greater root growth and the return to the soil of a greater volume of crop residues are both important considerations in protecting soil from erosion losses.

Farm mechanization is necessary for high total productivity in the U.S. because of scarcity of farm labor. Mechanization, particularly of tilled crops, has shifted land use to farms with more level topography and a soil pattern that is rather homogeneous. Large planting and harvesting machinery can be operated more efficiently in uniform soil and topographic situations. Mechanization has been a dominant factor in much of the shift from tilled crops to pasture or vice versa. Mechanization also increases yields on a given land area because planting, harvesting, and crop protection operations are performed at the right time, thus increasing crop yields.

Many superior cultivars of major crops have been developed in the past three decades. For example, they are high yielding and more resistant to lodging at high rates of fertilization and plant population than previously available strains. The widespread availability and use of these superior cultivars have been major factors in increased yields in the U.S. The control of disease organisms, insects, and weed infestations by using effective pest control systems has greatly influenced crop yields and land use patterns.

Major modification of the soil-water regime of potential cropland has been carried out in the last three decades by 1) draining excessively wet land, 2) irrigating drylands, and 3) decreasing bottomland flooding. The 1959 Census of Agriculture shows that nearly 102 million acres in 39 states are contained in more than 8400 drainage enterprises with areas over 500 acres in size. Within these enterprises, drainage modifications have been made on about 92 million acres. By 1967 about 39 million acres not covered by the Census had been drained by individual land owners. In 1972 the Soil Conservation Service estimated that 130 million acres, or about one-third of all crop land, is drained artificially. Many farmers have shifted tilled crops from rolling land to drained land and thus have reduced the erosion potential on the upland and terrace soils. However, some land areas that have been drained

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have proved to be undesirable for cropland and it would have been a wiser decision to have left them undrained.

In the three decades from 1939 to 1969 the acreage of irrigated land in the continental United States more than doubled, increasing from just under 18.0 million acres in 1939 to 39.1 million acres in 1969, most of it in the western water resources regions. Estimates based on work by Durost and Barton [15] indicate that increases in irrigated acreage accounted for between 5 and 8 per cent of the growth in farm output between 1930 and 1960. Another indication of the impact of irrigation on agricultural output is that the 7.2 million acres of irrigated land brought into production between 1949 and 1959 were roughly equivalent in productive capacity to the 25-30 million acres taken out of agricultural production during this same period for non-farm use and by the acreage allotment.

Up through June 1972, 1,060 watershed protection and flood prevention projects had been approved for operation under Public Law 566. These projects were designed to enable farmers to shift much land in flood plains from pasture and woodland to tilled crops. Including all the land in the watershed project (upland and bottomland), there has been a net decrease in land used for row crops. Farmers have shifted tilled crops from rolling land to bottomland, thus reducing the erosion potential on the watersheds [16].

Summary

Agricultural land use has undergone many revolutionary changes in the last three decades. Most of these changes have resulted in greater yield per acre, greater total agriculture output of crops and livestock, and a steady decline in acreage of harvested crops. It appears also that the net result of these land use changes is reduced soil erosion over what it would have been if these changes had not taken place. At present, and for the next few decades at least, American agriculture has a large unused productive land potential for the production of crops. There seems little reason for concern about the nation's ability to feed itself. By increasing agricultural output and shifting some land to vegetables and cereals, the U.S. has land potential to feed many times its present population.

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ALTERNATIVES TO PESTICIDES IN SOUTHEASTERN UNITED STATES

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SUMMARY

A critical review of alternatives to the use of pesticides in agricultural practice in the Southeastern United States is presented. The methods, their stage of development and case histories are cited.

INTRODUCTION

Pest management should be predicated on the totality of knowledge of all pest control methods and the ecological impact. Effective control measures should be those which consider the long-term ecological and economic aspects. The indiscriminate use of any single control method may produce undesirable and unintended side-effects[1]. On balance, the introduction of chemicals such as pesticides to agricultural practice has been beneficial. However, not all the effects have been positive. Problems have arisen, some quite serious, which detract from the benefits[2,3]. This is attributed in a large measure to the disruptive impact on the ecosystem[4]. The benefits of pesticides have been so evident that alternatives have not been evaluated with equal vigor. All practices, whether chemical, cultural, physical, genetic or biological, must bring about the most effective, least ecologically disruptive, pest control possible. Although alternative methods are sought, it is generally conceded that pesticides will be used to control pests into the foreseeable future[5].

The objective of this review is to examine alternatives to pesticides, particularly those which offer potential or have been utilized in the Southeastern United States.

CULTURAL METHODS

Pest control methods are effective because they either directly affect the pest species or adversely modify environmental conditions necessary for its survival.

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Cultural methods are routinely utilized in agricultural practice to reduce pest-related problems. These usually involve adjusting the time or manner of performing operations for the production of crops or animals, or in improving management procedures. Examples of methods[6-10] and the target pest species include:

(*i*) *Sanitation.* Destruction of crop refuse (boll weevil, bollworm, corn borer); cleaning of field borders (weed control); disposal of wastes (fly control).

(*ii*) *Rotation.* Crop rotation (fungal spores, bacteria, mites, insects and viruses, nematodes); animal rotation (cattle tick control).

(*iii*) *Farm management.* Land bank and fallowing (cyst nematodes); strip cropping (alfalfa aphid); fertilizers (chinch bugs, weeds); time of planting (southeastern corn borer, sugar-beet nematode); pest-free seeds (weed control, wheat nematode control); destruction of volunteer plants (potato aphids); destruction of alternate hosts (wheat and apple rusts, beet leaf hoppers, sweet potato weevils); destruction of early blooms (sorghum midge); tillage (grape berry moths); crop spacing (weeds); cleaning of farm equipment (weed control); trap crops (citrus red mite); regulation of plant stands (citrus pests); selection of site (various forest insects); thinning, topping, pruning and defoliating (tobacco hornworm, mite and control of dutch elm disease).

(*iv*) *Water management.* Irrigation and flooding, (root-knot and white-tip nematodes); impoundment and improved pond management (aquatic weeds, mosquitoes, biting midges); drainage (nematodes).

The southwestern corn borer, *Diatraea grandiosella*, has slowly migrated eastward and has been reported in western Tennessee and Alabama[11]. Cultural practices which increase exposure of the larvae to the environment and predators are effective in increasing overwintering mortality. Burying, *per se*, is not detrimental to the larvae but it prevents the moths from emerging from the soil. Early planting of corn lessens damage with the primary advantage being a reduction in girdling. Generally corn planted in Tennessee before May 1 is damaged less by girdling, but infestation and lodging are not consistently reduced in all years and locations.

The pink bollworm provides a classic example of a major cotton pest that may be controlled by cultural practices. The control program includes stalk destruction and deep plowing of the residue after the crop is harvested. Two factors, overwintering as larvae and a single host plant (cotton), make this pest highly susceptible to this practice. When cultural measures are used in conjunction with good agronomic practices the pink bollworm population may be reduced to low levels. Often damaging bollworm populations do not develop the following year.

Attacking the boll weevil and pink bollworm during the fall of the year is a biologically and operationally sound practice aimed at destruction of the diapausing populations. Only bollworms that are in diapause are able to survive the winter. This is the weakest link in the life cycle. A factor in the success of this method is that these two cotton pests do not develop large populations on wild or alternate host plants[12]. The great majority of the diapausing boll weevils leave the cotton fields for hibernation sites during the harvest period of late September and October. The adult requires a feeding period of 1 to 3 weeks to accumulate sufficient fat reserve to attain

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diapause or overwintering stage. Any practice which eliminates either food or breeding sites during this critical period will be detrimental to the weevil. The most important practice is defoliation of the cotton plants. This eliminates squares and young bolls necessary for the development of diapausing populations. The next most important practice is to harvest the crop as quickly as possible and then destroy the stalks. Destruction of plant residues, crop rotation, utilization of high potash fertilizers etc. have been effective methods of control of cotton diseases such as anthracnose, bacterial blight, fusarium wilt, root-knot nematodes and seedling diseases[13].

Cultural methods which control weeds in cotton fields are important. Production techniques which promote rapid crop emergence and growth tend to control weeds by shading. Some cultural practices permit the use of herbicide for weed control on alternate crops in a more effective manner than with a single crop. For example cocklebur is very difficult to control in cotton fields but relatively easy to control in corn fields. Hence, rotation and eradication are complementary. Disking or plowing six to eight times during a growing season effectively reduces Johnson grass rhizomes prior to the succeeding growing season. Similarly, plowing or disking every four weeks for two successive growing seasons has been reported to essentially eradicate nutsedge[14].

PHYSICAL AND MECHANICAL METHODS

Preventive and corrective physical and mechanical methods differ from cultural methods since they are intended specifically to control pests and are not routine agricultural practices. Their effectiveness lies in the fact that all biological species exhibit thresholds of tolerance with regard to temperature, humidity, sound, and response to various regions of the electromagnetic spectrum. The possibilities for control techniques involving the spectrum of radiant energy and devices such as light traps are especially promising[15,16].

Temperature is utilized in the control of soil-borne diseases caused by bacteria, viruses, fungi and nematodes[6]. Fire has been found to be an effective method of control of the alfalfa weevil, *Hypera postica*[17]. Seeds are often protected by storage at low temperatures (4–10°C) since most grain-infesting insects are inactive at these temperatures. Temperature may affect the susceptibility of host plants to virus infection, the time required for development of symptoms, and the degree of damage. The principle also applies in those cases where the majority of plants in a vegetatively propagated clone are infected[18].

A hot-water treatment, alone or in combination with a nematocidal dip, is used to treat plants contaminated with ectoparasitic nematodes such as *Hemicycliophora* sp. or *Criconemoides* sp. These pests are difficult to dislodge by mechanical means because their long stylets are inserted into the plant cells. Endoparasitic nematodes present with plant tissues or enclosed within the protective layers of plant parts require a penetrating chemical or physical agent to affect a kill. Heat is most commonly used. Externally applied heat is absorbed by the plant propagule and ultimately penetrates to reach the pathogens. Heat treatment is effective when the

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temperature level of nematode sensitivity is below that of the plant-tissue sensitivity. Examples of recommended temperature–time treatments found useful for control of parasitic nematodes include: Easter lily bulbs with spring crimp nematode, *Aphelenchoides fragariae*, 1 h at 44°C in a water and formalin bath; citrus rootstock with burrowing nematode, *Radopholus similis*, 10 min at 50°C; and grape rootings with root-knot nematodes, 30 min at 47.8°C, 10 min at 49°C, 5 min at 51.6°C, or 3 min at 53°C (refs. 9, 17).

Light traps employing ultraviolet or blacklight lamps are being evaluated to determine their effectiveness for attracting moths[19]. In one 113-square mile area in North Carolina, 370 traps were estimated to have exterminated 50 to 60% of the adult tobacco hornworm moths in one growing season. A trap density of three per square mile in combination with stalk cutting and insecticide treatment to prevent late season breeding of hornworms, further reduced infestation by about 80%. This moth reduction was measured at the center of the test area during the second year. About 20 times as many males as females were captured demonstrating the potential for decreasing mating incidence.

Other examples of blacklight traps for insect control include the protection of cabbage from the cabbage looper, *Trichoplusia ni*, and of celery from the celery looper, *Anagrapha falcifera*[8]. The European corn borer and the cotton bollworm can be significantly reduced by light traps if population pressure is not excessive. Damage to tomato fruit and foliage resulting from the attack of tobacco and tomato hornworms can be minimized[8]. The increase in yield of cucumbers from plants protected by light traps has been especially encouraging; populations of the striped and spotted cucumber beetle were reduced and the transmission of bacterial wilt was minimized. The benefit of the light trap is that it eliminates the need for chemical applications in those climatic areas where light attraction is consistently effective. Light traps may be used to attract moths and bring them into contact with chemosterilants.

Not all moths and flying beetles are attracted to blacklight sources. This limits the application of this control method. Further, the practice requires electrical power which may not always be available. The advantages are: no residues are left on crops; moth emergence is detected and this provides a means for timing of control measures; attraction occurs irrespective of the physical condition of the field; the method may be integrated with other control approaches (*e.g.* post season stalk cutting in tobacco)[16,19]; and it is low in operating cost.

RESISTANT VARIETIES

Plants or animals that exhibit less damage or infestation by a pest (disease, nematode or insect) than others under comparable conditions in the field are considered to be resistant. Selection and improvement results in a resistant variety which becomes an integral part of the pest-management program. One of the most important contributions of agricultural programs of the pre-DDT era was the development of resistant varieties. This method of reducing pest damage has been used extensively since the turn of the century. Originally the case for use of naturally resistant plants

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was economic; it added little or nothing to the grower's cost of production. Pollution control is currently a consideration.

With crops such as alfalfa, small grains and tobacco, it is the availability of resistant varieties which makes the difference between profit or loss. In other cases the resistance factor is even more important in that it makes culture of the crop possible. Stem rot of peanuts, rusts and smuts of cereals; anthracnose of watermelon; and fusarium wilt, mosaic, black shank, and black-root rot of tobacco are examples of the diseases which are primarily controlled by planting resistant varieties. Approximately 75% of the total acreage in agriculture production in the United States is currently planted with resistant varieties[10]. Varietal resistance to insects and other pests is classified into three broad categories: *Preference* (for oviposition, food or shelter), *antibiosis* (adverse effect of plant on biology of insect) and *tolerance* (repair, recovery or ability to withstand infestation)[20]. Secondary plant substances (terpenes, quinones, alkaloids) contribute to preference and antibiosis resistance mechanisms against insects and diseases[21].

A classical example of the use of plant genetics is the control of grape *Phylloxera* in Europe over the past 90 years. Highly resistant American varieties saved European viticulture[5]. A search for plants resistant to insects was conducted in California over a 10-year period beginning in 1881 (ref. 20). By the turn of the century, many programs were underway. These included: mildew resistance of grapes in France; late blight of potatoes in several European countries; rust resistance in wheat in Australia, England and the United States; and wilt resistance in flax, cotton, watermelon and cowpeas in the United States. These and many other programs are still being pursued actively today[22,23]. Each year new resistant varieties are introduced. Current research is being directed toward incorporating multiple pest resistance into crop varieties. Development and use of resistant host plants is one of the most effective methods of economic pest management in agricultural ecosystems.

A bacterial disease known as Granville became a limiting factor in production of flue-cured tobacco in North Carolina following the turn of the century. Losses in Granville County alone during the period 1920 to 1940 were estimated to be 30–40 million dollars. Intensive research to develop wilt-resistant tobacco was initiated in 1935. This effort culminated in the introduction in 1944 of a resistant tobacco variety of acceptable quality. Program cost was about $150,000. By 1948, the value of tobacco grown in the area of Granville was estimated to be $2,000,000. By 1964, 416,000 acres were devoted to the tobacco crop in North Carolina with an estimated value of $520,000,000. Approximately 95% of this acreage was planted in varieties which not only incorporated resistance to Granville wilt, but also to black shank. It is estimated that if resistant varieties were not available the yield would have been reduced to less than one-fourth[22,24]. These major tobacco diseases involve soil-borne pathogens. Effective chemical controls were not available and the effectiveness or practicality of other approaches, including rotation and related cultural practices, would have been limited.

Varietal resistance as a means of controlling cotton pests has generally been ignored until recently. Screening of available germplasm has recently proved to be

highly rewarding. The possibility of controlling *Heliothis* sp. and other lepidopetrous pests by incorporating high levels of gossypol and other pigments into commercial varieties appears to be especially promising. Plants having a gossypol content of 1.5% or more cause both larval mortality and inhibition in development of *Heliothis* larvae. Such levels have been attained in several lines. High gossypol content is undesirable in cotton seed because of its toxicity to non-ruminant animals. Considerable effort has been devoted to incorporating characteristics of low gossypol content into commercial varieties. This illustrates the necessity for a cooperative approach in developing varieties of cotton[12].

The spread of the boll weevil, *Anthonomus grandis*, throughout the Cotton Belt at the beginning of this century brought marked changes in the kind of cotton plant grown. The late, vigorous, long-staple upland varieties were rapidly replaced by early-maturing, short-staple types which were less susceptible to damage because of their shorter exposure period and thicker carpel walls.

Knipling[5] estimated in 1971 that $75,000,000 was being expended annually for control of the boll weevil. In spite of this expenditure, control is far from complete and the annual loss is estimated at $200,000,000. Indications of the weevil developing resistance to insecticides renewed interest in the development of resistant types. The U.S. Cotton Boll Weevil Research Laboratory was established in 1962 at State College, Miss., with the objective of finding new approaches to boll weevil control or eradication with less emphasis on use of insecticides.

Genetic factors contribute to resistance of cotton to the boll weevil. In the frego bract mutant type, the normally adherent bracts become flared and twisted. The frego types are less attractive for oviposition[25] and readily permit penetration of insecticides. Boll weevil oviposition suppression factors, attractants, feeding stimulants and repellents have also been found to be associated with resistance in cotton[26].

Discovery in 1954 of nematodes attacking soybeans in North Carolina was the first report of this pest outside the Orient[27]. Crop damage posed a threat to the United States soybean industry. Control of the soybean cyst nematodes has been difficult and multiple approaches have been necessary. Application of chemicals to the soil has not been economically feasible. Crop rotation of 2 to 3 years is effective, but results in limited production. Federal and state quarantines have been only partially successful. In 1957, some 2,800 soybeans varieties were screened for nematode resistance in heavily infested fields. Four varieties were found on which the nematode did not reproduce. The desirable characteristic of resistance was transferred to a commercial variety developed cooperatively by the Agricultural Research Service and the Agricultural Experiment Stations of Arkansas, Missouri, North Carolina, Tennessee and Virginia[27].

Disease-resistant vegetable varieties are especially noteworthy. A vegetable grower in the Southeastern States, by proper selection of such varieties, can now reduce the damage caused by such destructive diseases as fusarium wilt of cabbage, tomato and watermelon; common mosaic of beans; celery leaf blights; spinach blight, cucumber scab; and many others. In many cases, the farmer will not sacrifice the quality or productivity of his crop through use of a resistant variety[28].

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Heliothis zea is adapted to feed on a wide range of hosts and has been given common names associated with the crop attacked, *e.g.*, the corn earworm, the cotton bollworm, and the tomato fruitworm. The literature is extensive. Variation in earworm damage has been ascribed to variety, planting dates, spacings, date of maturity, soil fertility, concentration of feeding stimulant and nitrogen balance. Varietal differences have commonly been associated with husk characteristics, either extension or tightness. However, chemical differences also appear to be involved. The effect of either husk extension or husk tightness are explicable from knowledge concerning the feeding habits and cannibalistic tendencies of earworm. Either husk extension or tightness or their combination may ensure minimum damage to the developing grain, but have little or no effect on population dynamics, and therefore, represent a special case of tolerance rather than one of antibiosis[26]. Extensive research is needed to develop resistance (antibiosis) to leaf feeders.

The greatest forest disease resistance research is presently concentrated on the fusiform rust of southern pines. Agencies, both governmental and private, are engaged[39]. In North Carolina, a "rust nursery" approach is being used for mass screening of known seed sources of southern pines. This approach also permits estimation of the heritability of resistance in a natural population of southern and loblolly pine. Since 1954, a tree-improvement program has been underway in Florida. This involves screening of select slash pines for resistance to fusiform rust. Selection and field testing of slash and loblolly pines of one parent and controlled progeny are being studied for their resistance.

BIOLOGICAL AGENTS

Biological control involves the suppression of the reproductive potential of organisms through the actions of parasites, predators, or pathogens to restrict pest population at a lower average density than would occur if these were absent[3]. The interrelationships and differences between biological and chemical control are illustrated by the experience of the citrus industry in California. It once suffered a massive infestation of a mealy bug, cottony cushion-scale, *Icerya purchasi*, introduced from Australia on acacia in 1868. Two Australian ladybird beetles, *Rodolia cardinalis* and *Cryptolaemus* sp. provided the necessary predator–prey regulation. They reduced the mealy bug populations to levels at which they no longer constituted a major pest infestation. Unfortunately, cottony cushion-scale again reached major levels when extensive applications of DDT to citrus eliminated the vedalia ladybird[30]. This example of pest recurrence emphasizes an inherent risk in pesticide use. A catastrophic effect on the natural regulatory mechanisms may occur. While chemicals may temporarily diminish the numbers of a particular pest, they may also reduce its natural enemies. Subsequently, a population explosion of pests can occur before its natural enemies are able to recover.

Insects, like animals, suffer from disease attacks[31]. Under favorable conditions a disease may reach epidemic proportions for an insect species. Within a few days or weeks, it may reduce the species from a point of great abundance to one of scarcity.

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Insect diseases may be caused by protozoa, fungi, viruses and bacteria. During the last two decades, there has been an increasing awareness of the great potential of insect diseases as control agents. About 225 species of insect viruses have been isolated. Of these, the nuclear polyhedroses (107 species) and the granuloses (80 species) are candidates for effective insect control[32]. Green[33] reported over 300 insect viruses that can be utilized for control of specific pests.

The advantages offered by microbial pest control are:

(1) Insect pathogens in general, and viruses in particular, are very discriminating and infect only one species or members of closely related species[34].

(2) If conditions are optimum, the introduced microbial agents may spread of their own accord, resulting in wide-spread killing of the host in natural populations.

(3) Microbial insecticides are biodegradable and leave no residue or build-up in the soil, as occurs with many chemical pesticides.

(4) Most microbial insecticides are harmless to animals and plants and may be applied in heavy doses without damaging these forms of life[31].

(5) Microbial pesticides are generally compatible with other pesticides.

Selected examples of arthropod pathogens and the pests successfully controlled are: nuclear polyhedrosis (bollworm–budworm complex, cabbage looper, alfalfa caterpillar) and *Bacillus thuringiensis* (many caterpillar species). Others are being evaluated[34,35].

Limitations of microbial pest control are:

(1) Perhaps the greatest question concerning the use of microorganisms to control insect pests has to do with the timing of application in relation to environmental conditions. The effect of high humidity on viral diseases is controversial. Viral epizootics may or may not be related to wet weather. In the laboratory, an excess of moisture often leads to the outbreak of bacterial diseases. Low humidity is generally considered a limiting factor for the spore germination, infection and subsequent sporulation of the fungus on the host. High temperature generally accelerates the course of a disease. Much remains to be learned about the optimum time to apply the microorganisms.

(2) It is necessary to maintain the vitality and virulence of the infecting agent especially for those microorganisms not possessing a cyst or spore stage. The possibility exists that resistant populations will develop after prolonged use of microorganisms.

(3) The effect of heavy applications of entomogenous microorganisms on plants and higher animals needs to be considered. There appears to be little likelihood, that microorganisms naturally pathogenic to insects could cause serious injury to animals or plants.

(4) A microbial insecticide can be used against one species only. Mixed formulations have as yet not been widely tested.

(5) Of considerable importance is the effect that pathogenic microorganisms may have upon the insect parasites and predators of a pest. Few observations have been made, but enough has been learned to suggest that close attention must be paid to this relationship whenever the artifical dissemination of microorganisms is

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contemplated. Sometimes the insect parasites and the disease are related in a complementary or supplementary fashion. This has been observed in alfalfa fields infested with caterpillars of the alfalfa butterfly, *Colias eurytheme*. In fields where the polyhedral wilt disease is present but not abundant among the caterpillars, the smaller larvae may be parasitized by *Apanteles* while the larger larvae may be killed by the polyhedral wilt disease[31].

Environmental protection necessitates curtailment of direct herbicide application to aquatic system for weed control. This is intensifying the search for alternatives. Mechanical methods are costly, usually temporary in effect, and difficult to employ, particularly in canals. Biological control offers a potential alternative for extensive areas where the cost of chemical or mechanical practices would be prohibitive.

To date, biological control of weeds has been accomplished mainly by insects; but use of mites, snails, pathogenic microorganisms, fish, ducks and geese, manatees, and parasitic higher plants are under investigation[36,37]. Caution must be exercised before any animal is introduced for weed control. In the absence of their preferred food, they may become pests of alternate plant types.

Florida red scale, *Chrysomphalus aonidum*, and purple scale, *Lepidosaphes beckii*, were until recently the two most important armored scales on citrus. Control of purple scale by the introduction of the parasite, *Aphytis lepidosaphes*, has been reported[38]. Hymenopterous parasites represent the critical control factors for the Florida red scale. *Pseudohomalopoda prima*, the parasite attacking mature female red scale, is highly important. The most important parasite species appear to be *Aspidiotiphagus lounsburyi* and *Phospaltella aurantii* which attack male and second-stage female scales[39]. A special survey of Florida red scale and parasites was made between February and June 1967 on 104 groves. Parasites were identified as being either *P. prima* or *A. holoxanthus*. Parasitism by *A. holoxanthus* was very high. This parasite, which was introduced from California in 1960, appears to have much greater ability to survive adverse weather conditions than *P. prima*[40,41]. Partial to complete control has been achieved using these parasites.

Several species of parasitic insects were reared from field-collected larvae of the bollworm, *Heliothis zea* and the tobacco budworm, *H. virescens* in Mississippi[42]. The parasites belong to the families *Braconidae*, *Ichneumonidae*, and *Tachinidae*. The predominant species were two Braconids, *Microplitis croceipes* and *Cardiochiles nigriceps*. Parasites provided a high percentage of control on cranesbill, tomato, and spider flower. Observations were also reported on the effectiveness of *C. nigriceps* in controlling *H. virescens* on tobacco in areas of Florida and Georgia[43].

Parasitization by *Aphidius smithi* varies as a function of the age of pea aphid, *Acyrthosiphon pisum*. Susceptibility is highest at first instar stage. In California, this parasite has been propagated and widely released for effective control. Since 1962, this parasite has been found to be occurring in increasingly large numbers in clover and alfalfa fields in Kentucky[44].

Virus, Viron/H™, attacks only species of the genus *Heliothis* of which there are two major economic pests. One is *H. virescens*, the tobacco budworm and the other is *H. zea* commonly known as cotton bollworm. This virus has performed at

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least as well as commonly used chemical insecticides in 80 to 90% of the cases. Its greatest advantage lies in the fact that it is completely specific and is absolutely safe and non-toxic. This virus is reasonably compatible with some chemical insecticides. These can be sprayed in mixtures as long as the pH of the solution is neutral. The formulated form contains 126 billion inclusion bodies per ounce and a quart will control the bollworms on 10 acres of cotton with a light to moderate infestation. The application of this virus in practically every cotton-growing state was permitted by the Food and Drug Administration (FDA) in 1970 (ref. 33).

A biological control program for the control of bollworm and tobacco budworm was integrated into an overwintering boll weevil control program on cotton in the Mississippi Delta in 1965 (ref. 45). This program was designed to utilize biological control measures and omit chemical control during the growing season. The factors utilized in the program consisted of the naturally occurring predator-parasite complex and the application of the nuclear polyhedrosis virus. *Heliothis* control with biological agents was compared with a toxaphene-DDT-methyl parathion control using 25- to 30-acre plots. The initiation of virus applications was varied to evaluate the effectiveness of the virus against various ages of larvae. The *Heliothis* biological control program compared favorably with the insecticide program when virus application was initiated to coincide with hatches.

A study was conducted in Alabama in 1968 to determine the importance of fungus *Entomophthora* sp. as a natural control factor for field populations of the two-spotted spider mite, *Tetranychus urticae*. Studies of the distribution of this fungus revealed its presence in 14 of the 15 counties where collections were made. Average infection rate was 25% (ref. 46). Five epizootics of the pathogenic fungus were observed in two-spotted spider mite populations in Lee County, Ala. Each epizootic was characterized by a high degree of infection by *Entomophthora* sp., accompanied by a rapid decline in mite numbers.

Experiments were conducted in the state of Florida to evaluate the effectiveness of large fresh-water snails, *Marisa cornuarietis*, as a biological aquatic weed control agent. The snails controlled *Ceratophyllum demersum*, *Najas guadalupensis*, and *Potamogeton illineonsis* completely and *Pistia stratiotes* and *Alternanthera philoxeroides* partially. *Marisa* preferred submerged to floating weeds. Little damage was done by *Marisa* to 4- and 5-week-old rice plants, but younger rice was killed when the snails had no other source of food[47]. Except for its possible deleterious effects in rice-growing areas, *Marisa* was regarded as very promising for the control of aquatic weeds especially in confined bodies of water[48].

Alligatorweed, *Alternanthera philoxeroides*, is an extremely prolific plant which is most difficult to control and even more difficult to kill. It does not pose a serious weed problem in South America, where 40 to 50 species of insects act as suppressing biotic agents. Only one of these insects was known to occur in the United States and this insect, a flea beetle, belongs to genus *Agasicles*. During the fall of 1965 and spring of 1966, over 9,000 beetles were transferred to selected and approved locations throughout Florida, Georgia, South Carolina, and Mississippi. Frequent observations were made in the vicinity of the release sites and at no time was there any evidence

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that the beetle fed on any plant other than alligatorweed. The beetles prefer alligatorweed growing in the water. The results were promising[49] and have been extended. The possible use of herbivorous fish has received minimum attention in the United States. Common carp, *Cyprinus carpie*, may control some aquatic plants by keeping the water muddy, and, to a lesser degree by rooting out plants. In China, Japan, Israel, and Thailand the grass carp, *Ctenopharyngodon idellus*, has been used successfully for the control of rooted aquatics[37].

Since 1957, eight species of fish have been field-tested for effectiveness in aquatic weed control in Alabama. The Congo tilapia, *Tilapia melanopleura*, grass carp, and the Israeli carp, *Cyprinus carpio* have shown the best potential for weed control. In ponds, Congo tilapia, when stocked at rates of approximately 1,000 to 1,500 per acre, in three months controlled *Pithophora* sp., giant *Spirogyra*, *E. acicularis*, *E. densa*, *Hydrochloa* sp., *U. biflora*, and *Rhizoclonium* sp. Grass carp controlled *Chara* sp., *P. oviersifolius* and *E. acicularis* in one month when stocked at a rate of 20 to 40 per acre. 6- to 9-in. Israeli carp, when stocked at rates of 25 to 50 per acre, were effective in reducing or eliminating *Pithophora* sp., *Rhizoclonium* sp., *E. acicularis* but in some ponds required 2 to 3 years to effect control[50].

The species of fish receiving most of the attention in Georgia are: *Tilapia nilotica*, *T. mossambica*, *T. melanopleura*, *C. carpio*, and *C. idellus*. All observations on Chinese or grass carp, *C. idellus* were favorable[51]. In the spring of 1967, 2,000 grass carp were stocked in a 20-acre pond in Georgia that had a 5-year history of excessive growth of *Najas* and *Potamogeton*. Within 6 weeks, the grass carp was able to consume most of the rooted aquatic vegetation.

Parasites and predators are continually being colonized and evaluated for their effectiveness as control measures for various types of aphids, scales, moths and beetles[52].

STERILITY

The use of insect sterilization to control and eradicate pest populations is one of the revolutionary departures of modern entomology[53–56]. There are two ways by which the sterility principle might be used to control or eradicate insects. One method involves rearing, sterilization and release into the natural population so that the sterile members will compete with normal ones and thus lower the reproduction rate. Early experiments in sterilizing insects employed X-rays, but subsequently γ-rays from a cobalt-60 source were used. As an example, it is assumed that the natural population exists in an isolated area containing a stable population of two million insects with a 1:1 ratio of males to females in equilibrium with the environment and with the biotic potential canceled out by environmental resistance. For each generation, two million sterile males would be released to compete equally for mates. By the fourth generation, the ratio of sterile to fertile males competing for each virgin female would be 1,807:1; with equal competition 99.5% of these matings would be sterile[53].

Another method is to treat and sterilize insects in the natural population to

reduce reproduction. The chemical compounds which reduce or entirely eliminate the reproductive capacity are called chemosterilants. Chemosterilants may affect only one sex (male sterilants, female sterilants) or both sexes (male-female sterilants). United States Department of Agriculture entomologists and chemists had screened 3,000 materials up to 1962 and found that at least 50 of them produce sterility in insects. Apholate and aphoxide are among the most active chemosterilants currently under investigation[54]. When administered orally or by contact these compounds produce irreversible sterility without apparent adverse effects on the mating behavior and length of life of the insects. Insects which are ready for field testing, include fruit flies, mosquitoes, boll weevil, *Heliothis* complex, sugar cane borer, rice stem borer, pink boll weevil and cabbage looper[56].

Screw worms were brought to the vanishing point by the release of 100 sterile males per square mile per week on Sanibel Island near Fort Myers, Fla., but eradication could not be proved because the test area was not sufficiently isolated to prevent immigration of a few fertilized females from nearby untreated areas. Another experiment was performed on the island of Curaçao[55] where eradication was achieved on that isolated 170 square mile island. The apparent eradication of the screw worms from Curaçao supported the theory that screw worms could be eradicated from the Southeastern States by releasing sterilized flies. In July 1958, a large sterilized fly production facility was completed at Sebring, Fla. This establishment produced fifty-million sterilized flies per week, which were distributed over all infested areas in the Southeast (Florida, Georgia, Alabama, Mississippi, South Carolina, North Carolina). By 1958, the screw worm had been essentially eliminated from the Southeastern States, the major area of the continental United States in which this pest can overwinter, and no significant infestations of screw worms have since occurred[57]. The screw worms were irradiated with γ-rays using a cobalt-60 source[58]. This was one of the most successful controls of an economically important pest.

Eradication of the cotton bollworm from St. Croix, U.S. Virgin Islands, was attempted in 1968 and 1969, using the sterile-male release method[59]. Both attempts failed in the primary objective of eradicating the species. The reasons were the high ratios of sterile to natural males which caused the elimination of oviposition, and the high degree of locking between the released population and the native females.

A truly effective chemosterilant for the boll weevil has yet to be discovered. Some of the aziridinyl compounds, particularly apholate, induce a rather high degree of sterility in the males, but the mortality of treated insects is high and their competitiveness is reduced[60]. During 1962, apholate-sterilized male boll weevils, *Anthonomus grandis*, normal males and virgin untreated females were released in three experimental 1-acre plots of cotton in Virginia, Tennessee, and Lousiana in the ratio of 20:1:1 in each of five uniformly distributed points. A total of 8,850 sterile males released over an eight-week period prevented matings between the ensuing F_1 males and females. On the seventeenth week of the experiment, no egg or feeding punctures were found in two examinations of all the squares and bolls on plants in the field. Only in the Louisiana experiment was eradication of the population achieved[61]. The successful eradication in 1962 of an artificially induced infestation of boll weevils

prompted further studies. From June 17 through August 26, 1964, eleven weekly releases of apholate-sterilized male boll weevils were made in nine cotton fields that had been treated with insecticides in the fall of 1963, to reduce the population of diapausing weevils. An average of 8,200 males were released per acre in Baldwin County, east of Mobile, Ala. This release program reduced the number of oviposition punctured squares. Also, the percentage of infertile eggs, the number of live immature and adult weevils per acre in fruit, numbers of overwintered adults and the levels of infestation during the second year were considerably lower in the release zone than in the zone treated intensively with insecticides.

Effectiveness of apholate in decreasing the sperm viability of the male boll weevil was determined[62] in Misisissppi by allowing the weevils to feed on a diet containing 0.001 to 0.020% of the chemosterilant and on plants sprayed with 0.5 and 2.5% solutions. After both treatments, virgin females mated to treated males oviposited eggs with decreased hatchability and emergence of the F_1 progeny. At the higher levels of treatment, longevity of males was reduced. Repeated spray applications of the chemosterilant to plants, especially at the higher levels, caused phytotoxicity manifested by leaf necrosis, stunting of growth and cessation of square production. The male boll weevil can also be sterilized with tris-(1-aziridinyl)phosphine oxide (TEPA), either by feeding 1,500 ppm of TEPA in the diet for two days or by an injection of 3.5 mg (ref. 63). Lower levels of TEPA produced transitory sterilization. At the effective levels mortality was significant.

Three compounds, aphoxide, aphomide, and apholate, caused sterility in male and female house flies at concentrations of 0.5 to 1% in food given to the adults[64]. Of 97% compounds administered in granulated sugar or in fly food tested in Florida, only 27% caused sterility in adult house flies, *Musca domestica*[65].

Corn meal baits containing 0.5% of aphoxide (1-aziridinyl phosphine oxide) a chemosterilant, were applied on an isolated refuse dump in the Florida Keys for the control of house flies. Applications were made each day during the second week. House-fly populations were reduced from 47 to 0 per grid within 4 weeks and the percentage hatch among all eggs laid was reduced to 1% within 5 weeks[66]. House-fly baits containing 0.5% of metepa, methaphoxide, tris-(2-methyl-1-aziridinyl)phosphine oxide, were applied to the droppings in a poultry house in the suburbs of Orlando, Fla., for house-fly control. Applications were first made at weekly intervals for 9 weeks, then semi-weekly. Granular baits with corn meal as a carrier were the most effective[67,68].

The cotton bollworm, the armyworm, *Pseudaletia unipuncta* and the granulate cutworm, *Feltia subterranea*, can be sterilized with TEPA. Males of each species are sterilized when they are fed 53 mg of TEPA in a 10% sucrose solution. A dose in excess of 106 mg is required to sterilize female cotton bollworms and a dose of more than 53 mg to sterilize female armyworms and granulate cutworms[69]. Sterilization of the fall armyworm by apholate and TEPA has also been reported[70].

ATTRACTANTS AND REPELLENTS

Many insects find their food, their mating partners and favorable sites on which to deposit their eggs by an automatic response to various scent clues. Male moths, for example, can detect potential sexual partners at great distance. Not surprisingly, each species tends to have its own distinctive odor which facilitates the meeting of mating partners. Frequently insects can be attracted by means of a chemical. This is useful for pest detection purposes or to expose them to an insect pathogen, toxicant or a chemosterilant[71].

Attractants have been classified into three categories; sex, food, and oviposition lures. The type of lure is inferred or deduced from insect behavior and the designation given to such response is frequently uncertain. If exposure to a chemical causes a male insect to assume a mating posture, the chemical is probably a sex attractant, even if it is a synthetic and unrelated to any natural lure. Some entomologists believe that methyl eugenol, the attractant for the oriental fruit fly, *Dacus dorsalis*, is a sex attractant because the chemical attracts only the male. However, it also appears to be a food lure, because the flies avidly devour the chemical[72]. A similar example is the attraction of the cucumber beetle, *Diabrotica undecimpunctata howardi*, to cucurbitacin, a terpenoid compound present in its host plants[73]. Food-based or fermenting lures have a definite place in control operations. Disadvantages include lack of specificity (traps fill with many kinds of insects), attraction over only a short distance, rapid deterioration (especially of fermenting lures), and frequently inconsistent performance. In regard to oviposition lures, females have been induced to lay their eggs on, or in the vicinity of, certain chemicals. Materials that release ammonia are known to encourage oviposition in house flies. The apple maggot is attracted to decomposing proteins, such as egg albumin[72].

Chemical attractants and associated agents, such as stimulants and assertants, have been widely used for many years in studies of insect behavior. They have served many useful purposes as lures in traps, *e.g.* to sample insect populations; to determine relative densities from time to time and from place to place; to trace the movement of marked insects in dispersion and migration studies; to study survival of insects in their natural environments; and to study behavior associated with the search for mates and oviposition sites.

In the search for selective methods of insect control, many entomologists and plant protection personnel are seeking chemicals which elicit repellence. A repellent is a chemical that causes an insect to make oriented movements away from its source[8]. The distance the insect needs to move, however, is usually much shorter than the distance it does move in response to an attractant. Ordinarily, it only needs to leave or avoid a treated surface or at most move a few centimeters out of the effective concentration of repellent vapor. Less use has been made of repellents for the protection of animals and plants than for the protection of man.

Ultimately attractants must be tested in the field where they must prove effective despite a multitude of natural odors, colors, light conditions, and weather[72,74-76]. Examples of some potent synthetic attractants are cuelure, siglure,

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medlure and trimedlure for various types of fruit flies; gyplure for gypsy moth; and grandlure for cotton boll weevil[72].

In 1956, the Mediterranean fruit fly reappeared in Florida after an absence of 26 years. Following its initial eradication in 1929–1930, the on-tree annual value of the citrus crop had climbed to about 250 million dollars and that of all other commercial hosts of this pest was many million dollars more. It was estimated that if these flies were not eradicated the combined annual cost of control efforts, fumigation of exported fruit, and maintenance of quarantine and road blocks would approximate 20 million dollars exclusive of crop losses and decrease of consumer acceptance of the state's citrus products. The statewide eradication involved aerial spraying of protein hydrolysate and malathion. Quick action by state and federal agencies (Plant Pest Control and Entomology Research Branch, U.S. Department of Agriculture) and industry, along with good public support, made it possible to complete effective curtailment and eradication programs in a minimum of time[77].

Two terpene alcohols and two terpene aldehydes from male boll weevils were isolated and identified at the Mississippi State University in 1969 (ref. 78). These compounds are the components of the pheromone to which only female boll weevils respond in laboratory tests. In bioassays, mixtures containing all four compounds elicited a response by females equivalent to or better than that elicited by live males[79]. Absence of either alcohols or the two aldehydes from the mixture resulted in almost complete lack of response. The response to the mixture of synthetic compounds was identified to that obtained from corresponding mixtures of natural compounds. The extract of fecal material of boll weevils (both male and mixed sexes) produced a material highly attractive to females but not to males. The synthesized pheromone was named grandlure. This compound, however, had a very short life. Polyethylene glycol increased its life. This stable product became an agent in surveying boll weevil infestation[80].

The pine sawfly, *Diprion similis*, is a pest of eastern white pine. It was observed that large numbers of males swarmed toward females. Investigations were conducted to determine whether a sex attractant was involved. A virgin female was placed in the screened portion of a trap and tanglefoot was spread over another portion. The traps were suspended from trees in the infested areas. An average of 1,000 males were attracted in each of eight traps. A large number of males also fell to the ground. Some females did not attract males for an unknown reason. The male response was rapid. Many approached within 30 sec after the traps were placed. Traps positioned at an angle of 90° to the wind direction at the edge of the wood were consistently more attractive than those set in dense woods. Greatest activity took place from mid-morning to sunset. One trap with a virgin female exposed from 11 a.m. to 4 p.m. attracted more than 7,000 males. She continued attracting males at approximately 1,000 per day until she died on the fifth day, after which small numbers were still caught over the next three days. Males were lured 200 ft. from the forest over an open field. Chemosterilant-attractant mixtures can be effective in reducing or eradicating a field population of this insect[74].

Epidemics of the southern pine beetle, *Dendroctonus frontalis*, have occurred

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periodically throughout the southeast and in parts of Texas. A remedial method presently being tested employs frontalure (1,5-dimethyl-6,8-dioxabicyclo[3.2.1] octane), the sex pheromone, to aggregate southern pine beetle population on the trees to be harvested and/or treated with cacodylic acid, which checked brood development but does not harm non-target insect. In fact, the simultaneous aggregation and survival of predators and competitors has become an integral part of this control method. Aerial surveys monitor southern pine beetle activity. Infestations can be treated immediately by the crews performing the ground check. Few tools are needed and the amount of chemicals deployed does not surpass gram quantities per acre[81].

HORMONES

An approach to pest control is based upon the rapidly expanding knowledge of how insects rely upon hormones to regulate their growth, feeding, mating, reproduction and diapause or overwintering[76]. The primary candidate for control measures is the juvenile hormone that all insects secrete at certain life stages[82]. The potential utilization of this information for insect control depends upon the ingenuity with which man can supply a juvenile hormone to the insect at an unfavorable stage. The contact of a last-stage nymph, larva or pupa with a juvenile hormone induces morphogenetic damage. This results in the development of intermediates or monsters which are unable to mature and die in a short time. Investigations have revealed other important functions of the juvenile hormone in insects including diapause, reproduction, embryogenesis, sex-attractant production, and lipid metabolism[76].

The synthetic juvenile hormone analogue, *trans,trans*-10,11-epoxyfarnescenic acid methyl ester, successfully terminated adult diapause in several species of *Hemiptera*, including the box elder bug and the red linden bug[83]. Juvenile hormones are unquestionably deeply involved in the regulation of diapause and the possibility exists that further research may result in the development of antihormones which can prevent or even induce diapause.

A male *Pyrrhocoris* treated topically with 1 mg of dichloride compound, synthetic juvenile hormone, is able to transfer enough of this chemical to females by contact during mating to induce sterility. This novel method of transmitting sterility should have interesting field applications if similar chemicals affecting insects other than *Phyrrhocoris* are developed. Williams[82] believes that synthetic juvenile hormone eventually will prove to be most effective as an egg killer (ovicide). Ecdysone is another insect hormone which has the potential of becoming a selective insecticide. This substance initiates ecdysis (shedding of skin) or metamorphosis from one stage to another in the larval or nymphal development of insects. Overstimulation with ecdysone results in repeated metamorphosis without sufficient time for the accumulation of food reserves so that eventually the larva or nymph becomes exhausted and dies.

From the foregoing it is obvious that the application of morphogenetic compounds to immature insects can kill them by upsetting their development. The

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practical utilization of these compounds becomes attractive with the realization that these hormonal effects are specific to insects. In addition, these chemicals have no effect on other forms of life[76,82]. A further advantage is that insects cannot develop immunity against the compounds for if they did, they would become immune to the hormone that is essential to part of their life cycle. Since this discipline of pest control is still little explored, specific case studies are not available.

GENETIC MANIPULATIONS

The first attempt at control by the application of genetics involved the tsetse flies, *Glossina* sp. Interspecific crosses were made of *Glossina swynnertoni* and the reproductively but not sexually isolated *G. morsitans*. Viable but sterile offspring were obtained from such crosses, which competed with normal individuals for survival in the environment[56]. Many lethal genes exist in populations of insect species that have been subject to genetic analyses. Deleterious genes need not be lethal nor act immediately for effective control. Drastic reductions in insect numbers can be obtained theoretically by constant low-level mortality factors superimposed on populations already exposed to the stress of adverse environmental conditions as, for example, low temperature during hibernation. Three requirements are essential to the success of control measures utilizing the release of strains carrying unfavorable genetic characters: the factors must not prevent rearing under laboratory conditions; they must not interfere with mating ability; and they should act at particular times, such as during the hibernation or immature stages. It has been postulated on theoretical grounds that the eradication of the boll weevil could be achieved in a few years if males carrying two lethal genes were repeatedly released into field populations. It should be considered that such additional release of pests could temporarily increase the loss of the crop until lethal genes are inherited and come into effect. Although genetic methods seem to offer promising leads, considerable research is needed before such techniques can be incorporated at a practical level.

PREVENTION OF SPREAD

One of the methods by which weeds spread is through their inclusion with crop seeds. As early as 1821, Connecticut passed a law prohibiting the sale of grass seed containing Canada thistle and other weeds. The earliest vegetable seed laws were adopted by Florida in 1889. By 1941 all 48 states had seed laws. The federal seed act[84] requires, in part, that the following information be provided on seed labels in interstate commerce: percentage of pure seed of the named crop, percentage of other crop seeds, percentage of weed seeds, and the rate of their occurrence. Crop seeds cannot be sold for seeding purposes in most states if they contain noxious weeds in excess of a specified percent by weight of weed seeds, generally 2 or 3%. The model state seed law, used as a guideline for legislation by many states, provides a typical example of state regulations. Noxious-weed seeds are separated into two classes: prohibited (generally annuals) and restricted (seeds of perennial weeds). Seed

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laws at state and federal levels have been important in reducing the spread of weed species and in improving seed quality[84]. Seed certification is the system used to keep pedigree records for crop varieties and to make available sources of genetically pure, disease-free seeds and propagating material for general distribution. Without such a system, seeds tend to become contaminated and mixed and lose identity. Certified seeds contain relatively fewer weed seeds[85].

There are at present no practical and economical treatments to cure virus-infected plants in the fields. Methods of control, therefore, are generally directed toward preventing infection by eliminating the source of inoculum, by preventing spread of virus, or by developing varieties immune to the virus or immune to the disease they cause. The production and distribution of "virus-free" propagating material has proved highly successful in controlling virus disease in many crops. The term virus-free can be defined as free from the known and specified viruses for which tests have been conducted. The tactics of virus control depend upon integration of several distinct activities: the recognition and characterization of the virus diseases in each crop; the development of reliable indexing methods to retrieve any existing healthy stock, to sort plants that have been treated to eliminate virus, and to detect any symptomless carriers; the development of techniques to rid a few selected plants of virus and establish clones of virus-free foundation stocks where no healthy material is found; and, the enactment of measures such as certification programs to maintain the health of foundation stocks, and to secure effective distribution of their progeny to growers and nurserymen. In the United States, certification programs are individual state functions. A certification program for virus-free citrus stocks is presently used in Florida. Such programs tend to keep a control on the known viruses of crops propagated from vegetative stocks[18].

In agriculture, quarantine refers to the restraints or restrictions placed upon the transportation of animals, livestock, poultry, plants, fruits and vegetables, plant and animal products or other materials which are suspected of being carriers of agricultural pests. Such precautions are necessary, as many of the worst plant pests came from other countries and thrive here because of abundant food and few natural enemies. The tempo of international travel has greatly increased and with it the danger of spreading pests has also increased. The quarantine system is a necessary element of overall national preventive pest control programs[86]. Domestic quarantines between states, combined with treatment programs, have eliminated several pests from the United States. For example, Japanese beetle, *Popillia japonica*, has been under continuous regulation in the United States since 1919. Established infestation still does not exist west of the Mississippi River, and occurs only in isolated areas in the southeast. Control and quarantine programs have confined the gypsy moth, *Porthetria dispar*, to a few northeastern states although there are some 100 million acres west of the Mississippi River known to be susceptible to attack[8].

Publicly supported regulatory programs are an essential part of the overall effort to protect crops and livestock from pests. Various methods are used in eradication, containment and suppression programs; these include chemical, cultural and biological measures. Greater merit is indicated for large-scale alternative control

programs as compared to region-wide chemical spraying. Many of the alternative techniques of pest control are employed over larger areas than individual farms. Programs of state and federal agencies in cooperation with private agencies and individual farmers will be required in pest control.

The detection of pests and surveys of their distribution and abundance are essential prerequisites to rational control programs. The first principle of pest detection and surveys, as related to control, is that no measures should be undertaken against a pest unless it is known to actually be present above economic injury level. Often this basic premise is not followed.

In 1971, cotton insect scouting programs were conducted in ten southeastern states. Scouts surveyed 877,225 acres out of 10,421,000 acres under cultivation. Such programs have been in operation for 9 years in Alabama alone. Scouted cotton fields have averaged 200 more pounds per acre in lint than fields not scouted. A scout who has received special training by an extension service entomologist can keep growers informed of the following: when the infestation count is great enough to warrant starting a control program; when to expect hatch out of boll weevils or bollworms; and, how long to continue the control program into the fall. Scouts give farmers weekly written insect reports and also send infestation reports to county extension chairmen and to extension entomologists. Each week, reports are summarized and a copy sent to all county extension chairmen and other agriculturists in the state[87]. Although no information is available regarding the actual reduction of pesticide used, it is postulated that many applications are eliminated without economic loss. Surveillance can only be effective over large areas. Sufficient understanding of pest ecology and biology exists so that such programs can be promptly initiated. Extension services and agricultural universities can play an important role in such activities.

SAFER PESTICIDES

It is widely accepted that although alternative technology exists, conventional chemicals will remain the chief means of insect pest control for the foreseeable future[5,88,89]. The rationale for this lag in the use of alternative methods merits explanation. There has been a growing concern over certain known and potential threats to the quality of our environment because of the use of the broad-spectrum pesticides. This concern, however, has not been fully translated into increased commitment of resources toward search, development or large-scale testing of safer pesticides and alternative methods. Most of the widely used chemicals for control have been selected on the basis of optimum effectiveness against the pest and for maximum persistence.

The original DDT patent of 1939 covered a number of insecticidal analogs[88]. These included methoxychlor, ethoxychlor and methylchlor. All of these compounds are persistent insecticides effective against a wide spectrum of insect pests and they are relatively inexpensive. DDT is the most stable and has had the most extensive use, whereas methoxychlor has been used on only a modest scale, and ethoxychlor

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and methylchlor not at all. These DDT-related compounds are rapidly degraded by the multifunctional oxidases of higher animals and converted to water-soluble compounds. DDT is not. Similarly, the related compounds are less toxic to fish. Ethoxychlor, methylchlor and other biodegradable derivatives of DDT merit further investigation as replacements for DDT and other persistent and non-biodegradable chlorinated hydrocarbons. Safer analogs (fenthion, ronnel, dicapthon) exist for methyl parathion, the most commonly used organophosphate. Consideration should also be directed toward the effect of these pesticides on the natural enemies of pests and beneficial insects[90].

INTEGRATED CONTROL

Integrated control combines several agronomic practices and pest control methods. The total effect of these combined methods is synergistic rather than additive. Integrated control is predicated on a fundamental ecological basis[91]. The concept includes appropriate combinations of pesticides, natural enemies, insect pathogens, cultural treatments, etc.[30]. It emphasizes the ecosystem and stresses economic levels[92].

A large-scale experiment is currently underway to eradicate the cotton boll weevil. The test area is 150 miles in diameter and is located around Gulfport, Miss. This two-year study will end on July 1, 1973. At that time researchers will have determined if eradication is feasible, and what the cost will be. Presently it is estimated that the total cost of eradication might be about $275,000,000. For the first time, treatment involves at least six simultaneous operations. These include in-season spray, as needed; a series of reproduction–diapause sprays in the fall to prevent over-wintering; defoliation; stalk shredding; and pheromone traps for males to prevent reproduction by surviving males. In addition, continued experiments with frego bract weevil resistant cotton, and temik systemic insecticide will be part of the program. The chief weapon will be diapause control by a series of up to seven fall sprays applied mainly by five helicopters in core zone, Columbia, Mississippi, and the first buffer zone, spilling over slightly into Alabama and Louisiana. Properly timed, this treatment can kill up to 99% of weevils entering hibernation. Chemicals used will be ultra-low-volume guthion or malathion, depending upon the environmental hazard involved. In the spring, adhesive-coated traps baited with grandlure will be placed on fence lines. These traps should catch about 80% of the emerging weevils. A single application of insecticide before square drop should kill about half of the surviving weevils, without permanently suppressing beneficial insect populations. The sterile males will then be released at a density of 50 to 200 per acre for several generations, and theoretically should reduce the native population by 98% with each generation[5,93]. If the eradication of the boll weevil should eventually be possible at a cost comparable to the annual losses for just 1 year, such a program would be one of the best investments the cotton industry could make. Perhaps even more important, the elimination of this insect would be the greatest single contribution that could be made in the foreseeable future toward the goal of reducing environmental pollution caused by the use of broad spectrum insecticides.

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Recent unpublished theoretical studies suggest that the mass production and programmed releases of one or more species of selective *Heliothis* larval parasites may also provide an effective and highly selective means of managing *Heliothis* populations. Relatively little is known about the numerical relationship between parasites and their hosts. However, based on a theoretical appraisal, there is good reason to believe that it is well within the realm of feasibility to mass produce and release sufficient selective parasites to truly manage insect populations like the *Heliothis* species. This system of insect population management should have its maximum efficiency when the host insect populations is high and should have diminished efficiency when it is low. This is just the reverse of the potential efficiency of the genetic approach. Therefore, the parasite release technique and the genetic technique may eventually prove to be highly complementary when they are integrated into one system of suppression. Environmental factors that induce and terminate diapause in *Heliothis* should also be elucidated to aid non-chemical control[94]. Insect pathologists are making considerable progress in developing microbial agents which may further strengthen an integrated approach.

Control of hornworms, *Protoparce sexta* and *P. quinquemaculata*, on tobacco with insecticides is not completely satisfactory in North Carolina. When *Polistes* wasps were induced to nest in shelters erected around the field, populations of fifth-instar hornworms were reduced by about 60% and damage by 76%. One-fifth of the recommended rate of insecticides TDE or endrin, applied as top sprays gave reliable and adequate control of both hornworms and budworms. This was true whether insecticide was applied every two weeks on a preventive schedule or only when counts indicated treatment was needed[95]. An integrated program would be more economical than present systems and would reduce residues to a fraction of the present levels.

The introduction of the beetle, *Agasicles* sp. as a biological control agent has been an added deterrent to the growth of alligatorweed, *Althernanthera philoxeroides*, through the Atlantic coast states. However, floating mats have been controlled in only very small local areas where herbicides have not been used. The recommended chemical control of alligatorweed is two or more treatments of silvex. Alligatorweed may be controlled with less herbicide in the presence of large populations of alligatorweed flea beetles. A dense mat of alligatorweed was treated with silvex and a beetle population of one adult per 2sq. ft. of mat was introduced when regrowth was 2 to 5 in. high. The beetles showed a feeding preference for the young regrowth over the more mature non-treated alligatorweed and maintained sufficient feeding pressure to eliminate the floating mat growth[96].

Integrated control today has acquired greater acceptance than when it was proposed 15 years ago. Broadly, it refers to integration of all crop protection procedures. Integrated control programs in general required a higher level of scientific background when compared to chemical control. At least a minimum level of information is usually needed regarding the following points: the general biology, distribution and behavior of the key pests; an approximation of the pest population levels that can be tolerated without significant crop loss; a rough evaluation of the times and places of occurrence; and the significance of the major predators, parasites,

and pathogens present; and information on the impact of the use of pesticides, insecticides, herbicides, and fungicides, as well as other control measures on natural enemies, and on natural and agroecosystems.

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Integrated Pest Management in China

by Robert L. Metcalf
and Arthur Kelman

China's 5,000 years of continuous, recorded civilization provide an unequaled perspective on pests and pest control. During this time, the Chinese have experienced almost every pest problem incident to agriculture and have practiced an astonishing array of pest control methods. The Western world has remained largely unaware of some of these approaches because of cultural and linguistic barriers, as well as our missionary emphasis on teaching in lieu of learning.

Today the West recognizes that satisfactory pest control is not a simple matter of routine application of pesticides, but rather a far more complex ecological effort. This makes it important to understand the experience of China, where some of the principles of integrated pest management (IPM) were enumerated over a thousand years ago.

The earliest organized efforts in Chinese insect control came with the depredations of the migratory locust, *Locusta migratoria manilensis*. Recorded locust plagues date back to 707 B.C.[1] Since then, more than 800 outbreaks have occurred in various parts of China, chiefly in the flood plains of the Yellow, Huai, and Chang Jiang (Yangtze) rivers and in the coastal regions to the south.[2] Successive outbreaks of locusts in a given locality have occurred every 3 to 15 years and lasted from 12 to 30 months.

The severity of the problem can be judged by the 1929 outbreak, which devastated more than 11 million acres of cropland, causing illness, starvation, death, and wholesale migration from the affected area.[3] Another disastrous locust outbreak occurred in 1938 when Nationalist soldiers destroyed the dikes along the Yellow River and locusts breeding in the flood plain caused damage in about 140 counties in ten provinces.

The earliest record of locust control dates back 3,000 years to a Shang dynasty (1523-1027 B.C.) poem, which describes the use of flames to destroy locusts. About 2,000 years ago in the Han dynasty (202 B.C.-A.D. 220), Wang Zhong (Wang Chung) described the use of open ditches to trap immature locusts. In A.D. 2, government officials offered bounties to peasants for collecting locusts. During the Tang dynasty (618-906), burning and trapping were successfully combined. During the Song dynasty (960-1279), the digging of locust eggs from the soil was described, and in

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1182 a law required citizens to collect and destroy locusts. This is very likely the first example in the world of a legal requirement for pest control.

By the Ming dynasty (1360-1644), the locust's behavioral traits, such as migrating upwind and early in the morning during heavy dew, its reluctance to fly at dusk or in the afternoon after mating, and its tendency to fly low after rain and toward flames, were described in simple texts and diagrams. Around 1600 Shen Guangjing called for preparations for locust invasions at a national level. Other innovations of this period included the planting of legumes, which locusts do not eat, and the herding of ducklings in fields to act as biological control agents.[4]

In ancient times, Chinese peasants were virtually helpless in combating the recurring locust plagues. Confucius (551-479 B.C.) regarded locust outbreaks as natural calamities and part of heaven's will. Despite advances in knowledge in the subsequent two millennia, effective locust controls only became available after the Revolution in 1949 when China began to mobilize rural manpower on a vast scale to combat the locust menace.

During the early 1950s manual destruction was practiced extensively. Locust eggs were dug up in winter and destroyed; trenches 20-30 kilometers (km) long were dug and young locusts driven into them and buried. Thousands of peasants encircled infested areas and killed locusts with bamboo brooms and locust swatters made from shoe soles nailed to wooden poles.[5]

Dusting with benzene hexachloride (BHC) began in 1951, and the use of aircraft for dispersal increased from 13.7 percent of locust-infested areas in 1958 to about 54 percent in 1960 and about 70 percent in 1963.[6] By this time the Chinese realized that they had relied too heavily on aircraft application of insecticide, which was not only costly but also had deleterious effects on beneficial insects and environmental quality. Moreover, the use of insecticides had weakened locust control organizations and delayed the accumulation of sound ecological information about locust control.

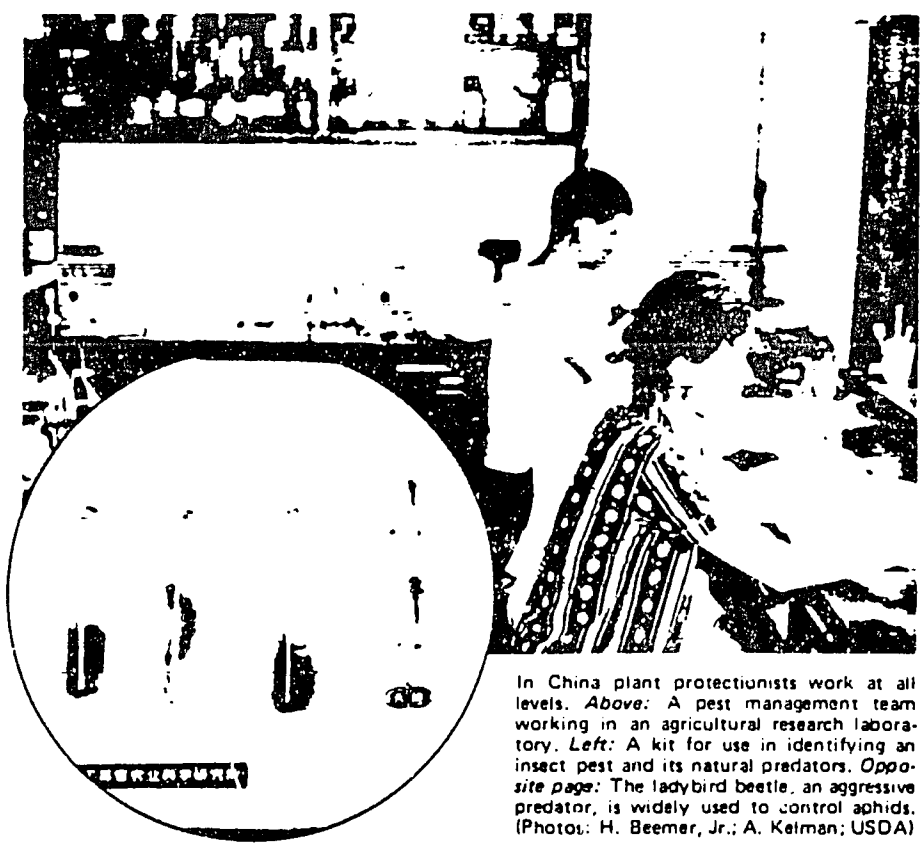
As a result, the use of aerial spraying was curtailed and by 1975 was virtually abandoned.[7] Yang Xiandong, vice-minister of agriculture, said in 1963 that the density of locusts had been reduced but the area of infestation had not decreased.[8]

More than 120 million persons participated in pest management programs for migratory locusts following a major outbreak in 1951. Primitive methods of surrounding, whipping, and burning locusts were supplanted gradually by more ecologically oriented efforts directed by stations surveying locust-breeding grounds and forecasting outbreaks on the basis of meteorological conditions. From 1958 on, enormous efforts were made to convert breeding areas in reedy, riverside flood plains into rice paddies, forest belts, and pastures. More than one million hectares (ha) of mountainous farmland in the Yellow River valley were converted into terraced fields. Four million check dams and 27,000 small reservoirs were constructed on small tributaries to control flood surges, and trees and grasses were sown on 4 million ha.[9] This campaign represents the most extensive pest management program of all time.

Today, rather than relying primarily on insecticides for locust control, China has developed an imaginative and practical approach for the environmental control of locusts that knits together biology, meteorology, water management, and cultural practices and relies heavily on forecasting.[10]

Importance of Plant Protection

China is still an agrarian society. Four-fifths of its population reside in rural areas where they engage primarily in producing food and fiber for themselves and urban dwellers.[11] Thus, agriculture is China's most important activity, and its farms currently produce enough food to feed about one billion people, or more than one-fifth of mankind. Scientists and agriculturists who have visited China since 1972 have commented, almost without exception, that the Chinese people appear exceptionally healthy and well nourished.



In China plant protectionists work at all levels. *Above:* A pest management team working in an agricultural research laboratory. *Left:* A kit for use in identifying an insect pest and its natural predators. *Opposite page:* The ladybird beetle, an aggressive predator, is widely used to control aphids. (Photos: H. Beemer, Jr.; A. Kelman; USDA)

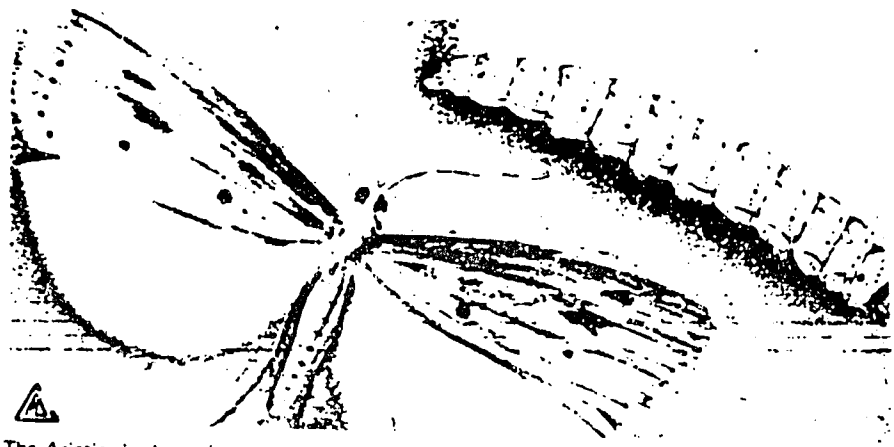
China has only about 107 million ha of arable land (compared with 156 million ha in the 48 contiguous United States), yet China is essentially self-sufficient in food production.[12] The success of plant protection and improved agronomic practices can be gauged by the increase in grain production from about 113 million tons in 1949 to 175 tons in 1974.[13] In comparison, the United States produced about 194 million tons in 1973. In 1976 China imported about 4 million tons of wheat, but this was partially offset by the export of about one million tons of rice.[14] These figures, as well as the observations of visiting scientists, indicate a highly successful and expanding agriculture.

China has attained virtual self-sufficiency in agriculture largely because of the enforcement of Mao Zedong's dictum: "Take agriculture as the foundation." Thus, hundreds of millions of man-years of effort are concentrated in rural areas, and large monetary resources are channeled into food production.

The financial commitment of China's leaders to agriculture has been estimated at U.S. $5 billion annually.[15] Agricultural production has been bolstered by extensive double and triple cropping in Central and South China, vast terracing and irrigation schemes in the North China Plain, and the development of area fertilizer programs to ensure optimum crop fertility.[16] It appears that crop yields and production have now been pushed close to their natural limits.[17] Therefore, the great challenge for the future will be to cope with a natural population increase now estimated at slightly over 1.5 percent each year. This population growth will require about 4 million additional tons of grain annually and ensures that agriculture will remain an area of paramount concern.

Protecting plants from pest attack is an obvious way to increase the available food supply without creating new agricultural land, improving irrigation, or increasing fertilizer production. Indeed, China's success in maintaining self-sufficiency in food production will be a measure of its achievements in controlling plant diseases and insect pests.

Detailed recent data are not available on crop losses from pest attack in China. However, in 1937 it was estimated that



The Asiatic rice borer (moth and larva). Although the precise magnitude of pest damage to Chinese agriculture is unknown, it is clear that losses are significant enough to warrant major governmental efforts to curb them. A 1967 estimate places the loss of rice production to insect pests at 15 percent. (Photo: USDA)

insects and plant diseases caused a 10-20 percent reduction of Chinese grain crops.[18] Another, more recent report in 1962 by the Bureau of Plant Protection of the Ministry of Agriculture suggested that in seriously affected areas grain losses were about 10 percent, cotton 20 percent, and fruits 30 percent of total production.[19]

In 1967, in a thorough compilation of pest losses in agriculture, H. H. Cramer presented data for crop losses in the People's Republic of China based largely on comparable data from Southeast Asia and the U.S.S.R.[20] These data suggest that the percentage losses to insects and plant diseases respectively are: rice, 15 and 8 percent; corn, 12.4 and 9.4 percent; wheat, 5 and 9 percent; cotton, 16.1 and 12 percent; sugarcane, 20.1 and 19.2 percent; apples, 13.2 and 13.7 percent. The accuracy of these loss estimates may be subject to question because they were 10 to 20 years out of date and did not allow for the immense progress made in plant protection in China under communism. Moreover, the possibility that crop losses to pests in China are significantly higher than in the United States is not substantiated by the observations of American scientists who have visited China recently.[21]

Although the precise magnitude of pest damage to Chinese agriculture is unknown, it is clear that losses are significant enough to warrant major governmental efforts to curb them. In 1958 the Ministry of Agriculture's Bureau of Plant Protection planned for thorough control of plant diseases and insect pests on 12.03 million ha of cropland in 18 provinces and municipalities.[22] Included were 3.6 million ha of rice, 1.6 million ha of wheat, 4.1 million ha of miscellaneous grains, 2.4 million ha of cotton, and 0.22 million ha of fruits and other economic crops. It was estimated that this control program could save 1.25 million metric tons of grain and 90,000 metric tons of cotton.

Such strenuous efforts have had substantial effects, and in April 1960 Vice-Premier Tan Zhenlin reported to the Second National People's Congress that substantial blocks of farmland had been freed from such pests and diseases as aphids, red spider mites, locusts, armyworms, rice borers, and wheat smut.[23] In 1962 Vice-Minister of Agriculture Yang Xiandong said that pests on 27 million ha were controlled by pesticides and that more than 2.67 million tons of grain and had been harvested as a result.[24]

Plant protectionists work at all levels of government. At the commune and brigade levels, they diagnose plant health problems, forecast outbreaks of pests, apply control measures, and organize demonstration plots. Sometimes a plant protectionist, together with a veterinarian and a paramedic ("barefoot doctor"), is assigned to a production brigade.

More commonly, plant protectionists and agronomists function as a special research group in a commune. In Shaanxi province, for example, 50 percent of the communes are reported to have such teams, as well as simple laboratories designed specifically for crop protection work. These are equipped

with microscopes, manuals for the identification and control of plant diseases and insect pests, reference collections of common insects and diseased plant specimens, and beautifully detailed posters illustrating the life cycles of important pests. Facilities for culturing organisms used in biological control of insects are sometimes available.

The plant protectionists are usually enthusiastic, dedicated, and well acquainted with the applied aspects of their disciplines. They are almost unique in the cooperation and rapport they have with peasants, who regard the control of plant diseases and insect pests as one of their primary responsibilities to the state and their communes.

Pest Control Technology

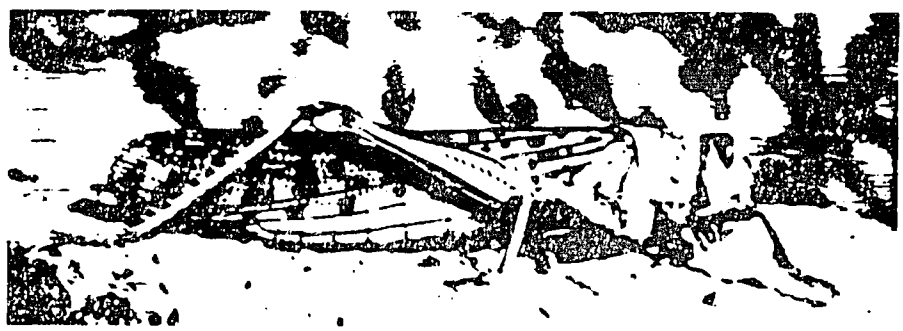
The most successful aspects of plant protection research in China have been the large-scale development and implementation of programs for practical integrated pest management (IPM--see box). In China, as elsewhere throughout the world, the need to develop IPM programs for major agricultural pests is urgent. The strategy of single-factor pest control interventions using insecticides that seemed so promising in the post-World War II era has become increasingly less attractive because of the development of resistance to insecticides by hundreds of species of important insect pests, disturbances of agro-ecosystems that have resulted in the appearance of devastating secondary pests, widespread environmental pollution by persistent and toxic chemicals, and rapidly increasing costs of pesticides.

IPM has a higher social priority in China than in any other part of the world, and it has brought steady and sometimes spectacular success to agricultural production and crop protection.[25] The following sections review China's major pest problems and methods of control.

INTEGRATED PEST MANAGEMENT (IPM) is the evaluation and consolidation of all available techniques into a unified program to manage pest populations so that economic damage is avoided and adverse side effects on the environment are minimized. It involves determining means of modifying the life system of a pest to reduce its numbers to tolerable levels, applying biological knowledge and current technology to achieve the desired modification, and devising procedures for pest control suited to current technology and compatible with economic and environmental quality aspects. (For a discussion of IPM, with an emphasis on the United States, see Robert van den Bosch, "The Pesticide Problem," Environment, *May 1979.)*

Migratory Locust Program

The locust program at Weishan Lake, Shandong province, is typical of the efforts that have been made.[26] The physiography of the area was analyzed, and in the 1960s, with 40 million man-days of labor and 550 million cubic meters (m^3) of concrete, the landscape was transformed by building 423 irrigation systems with 21,552 ditches having a total length of 15,492 km. This system prevented flooding in 39,000 ha and resulted in a good harvest despite 100 rainless days. In 1973, 58,890 ha were planted with rice, and 8,190 ha around the rice fields were planted with shade, fruit, and medicinal trees. This program largely eliminated locust infestations in the region by destroying breeding areas. It also reclaimed thousands of hectares of arable land and improved the local environment.



Recorded locust plagues in China date back to 707 B.C. The first organized efforts in Chinese insect control were aimed at combating depredations of the locust. (Photo: USDA)

Flight behavior in the locust's solitary and migratory phases has been carefully analyzed. Most migratory locusts fly at 15–20 m height, and some cover 25 miles or more in a single flight. The female's flying speed is greater than that of the male. At 19°C the averages were 4.7 meters per second (m/sec) for males and 3.7 m/sec for females; at 29°C the figures were 7.4 m/sec for males and 5.0 m/sec for females. Females were found to outnumber males by 10-37 percent, and it is believed that females play the leading role in setting the course of the migration. Chinese entomologists believe that the reflection of moonlight from lakes and rivers is the positive phototropic response that guides locusts to the adjacent breeding grounds. They also believe that the migratory flights are triggered by the arousal of the mating instinct as a result of moonlight and other appropriate environmental conditions.[27]

As an indication of the paucity of information in the Western world about Chinese insect control, B. P. Uvarov in his authoritative *Grasshoppers and Locusts* (1977) cites only eight Chinese references about *Locusta migratoria manilensis.*[28]

Biological Control

Biological control, a basic component of IPM programs, consists of introducing and encouraging natural enemies to regulate insect pest populations.[29] The natural enemies involved may be insect predators and parasitoids, as well as a variety of insect pathogens—bacteria, viruses, fungi, and nematodes.

Biological control has been widely and effectively used in China since the Cultural Revolution and has, in its various manifestations, become an integral and widely practiced component of IPM programs in the culture of cotton, corn, rice, fruit and vegetable crops, and forests.

The pink bollworm (shown here on a cotton boll) is capable of destroying whole fields of cotton. In China, an indigenous wasp which parasitizes overwintering pink bollworms is mass-reared and let loose in barns to destroy bollworms pupating in stored cotton seeds. (Photo: USDA)

The vigor of Chinese biological control efforts is apparent in the widely developed and effective programs for the culture and mass release of the hymenopterous parasitoids *Trichogramma* and *Anastatus*, in the practical utilization of coleopterous predators such as *Coccinella septempunctata*, and in microbial control with the bacterium *Bacillus thuringiensis* and its exotoxin, and with the fungus *Beauveria bassiana*. Much of the groundwork for the success of these programs was probably developed during the period of close association with the U.S.S.R. during the 1950s when many Chinese made extended visits to the Soviet Union.[30]

Trichogramma. Chinese entomologists have identified 12 species of these egg parasites, which are tiny wasps about 0.4 mm in length and weigh about 4 μ micrograms (μg).[31] *Trichogramma* have been characterized as living insecticides, since the adult female wasps have great mobility and highly developed searching capacity for the eggs of lepidopterous pests. Four species of *Trichogramma*, (*T. dendrolimi*, *T. australicum*, *T. ostrineae*, and *T. japonicum*) are mass-produced in special institute laboratories and communes.

The parasitic wasps are cultured on the large eggs of the giant silkworm moths or on the eggs of the rice moth. As many as 175 *Trichogramma* have been reared from a single giant silkworm egg, and the average is about 60.

In commercial production large numbers of giant silkworm cocoons are placed on an automated belt that is rotated to place newly emerged virgin female moths in a convenient position for collection. The moths are passed through an electric meat grinder, which squeezes out the intact eggs. These are stored and can be used over a period of time for parasitoid production. The eggs are cleaned, dried, and glued onto paper cards, either for immediate use or for short-term storage. The cards are placed in large glass cages or alternatively in outdoor cages containing literally millions of adult wasps, whose eggs are laid in the silkworm eggs on the cards.[32]

After parasitism of the eggs on the cards, the latter are ready for release at carefully calculated dosages. It is important that the emergence of the *Trichogramma* wasps from the egg cards coincides with the egg-laying patterns of the pests to be controlled. Release rates of *Trichogramma* in China are high compared with those used in previous attempts in other parts of the world, which undoubtedly contributes to the high degree of control obtained.

Several major insect pests are controlled with *Trichogramma*, which are an integral part of IPM strategies. European corn borer, *Ostrinia nubilalis*, in Jilin province was controlled by *Trichogramma* releases in programs that covered over 34,000 ha in 1974. The release rate was about 230,000 to 310,000 per ha at about 90 points per mou (1 mou = 0.066 ha) beginning just before the corn borer eggs were laid and during the peak egg-laying period. The cost was stated to be slightly more than 2 yuan per ha.[33]

Trichogramma also play an important part in IPM programs for managing the pink bollworm, *Pectinophora gossypiella*; the sugarcane borer, *Diatraea saccharalis*; rice leaf roller, *Cnaphlocrocis medinalis*; the spiny pine caterpillar, *Dendrolimus sibericus*; and other lepidopterous pests. A high degree of technology has been developed for the rearing and mass release of the four important species of *Trichogramma*.

The generally successful results come from suitable production and release methods, adequate short-term prognosis of weather conditions and target insect status, and use of the most effective *Trichogramma* species or strain for the area and crop involved. In general, stable control as good as or better than that from the use of chemical insecticides was reported.

Obviously, the successful use of *Trichogramma* is incompatible with the regular usage of broad-spectrum insecticides. The successful employment of *Trichogramma* in Guangdong province, for example, has cut insecticide usage by half or more. This was reported to be welcomed enthusiastically by farm workers because personal hazard from pesticide poisoning was substantially reduced.[34]

Coccinella septempunctata. This large and aggressive ladybird beetle has been widely transferred from natural vegetation into cotton and citrus for the control of aphids and leaf rollers.

Dibrachys cavus. This indigenous wasp parasitizes overwintering pink bollworms and has been mass-reared and liberated in barns in Shanghai and Shaanxi province to control pink bollworms pupating in stored cotton seeds.[35]

Use of this parasite has been an important part of the cotton IPM program.

Ducklings. A particularly innovative program of biological control using young ducklings as predators has been developed by the Zhongshan University Institute of Entomology. Ducklings are herded through rice fields in flocks of 1,000 or more and voraciously consume a variety of rice pests, including the rice grasshopper, the brown plant hopper, green rice leafhopper, and the rice stem borer.

Although this is an ancient Chinese practice, it is supported by meticulous research on predator/prey ratios and duck biology. For example, a single hungry duckling was found to consume about 200 insects per hour. In the Daxia Commune of Guangdong province, about 3,900 ha of rice are protected each year by about 220,000 ducks that are herded through the early rice crop by 853 duckherders. The pest population is reduced by 65-70 percent. This basic program is supplemented by the liberal use of *Trichogramma* and *Bacillus thuringiensis.*

The amount of insecticides applied on early rice decreased from 75,427 kg in 1972 to 34,112 kg in 1974 and to only about 6,700 kg in 1975. This program is very popular with peasants working in the field, who strongly prefer a pesticide-free environment, and presumably with the ducks as well.[36]

Microbial controls. The utilization of insect diseases in control programs is practiced on a large scale in China. Millions of metric tons of formulations of the spore-forming bacterium *Bacillus thuringiensis* (BT) are applied to rice, corn, cotton, vegetables, and forests for the control of lepidopterous larvae. BT is produced by both liquid fermentation and semisolid lower-yield fermentation methods using damp peanut and soybean meal in shallow baskets. The latter is cheaper and better suited to local commune production, and the output is standardized by testing before use.

BT applications were stated to produce 90-100 percent kill of pine caterpillar and 80-100 percent kill of cabbage armyworm, *Barathra brassicae*. BT is highly compatible with other biological control methods, such as mass release of *Trichogramma*, and because of its safety, is popular with peasants.

The fungus *Beauveria bassiana* has been described for many years as a possible microbial control, but its use has not been developed in the West. However, a strain attacking the European corn borer has been successfully used in Jilin province in conjunction with *Trichogramma* on more than 60,000 ha.[37]

The fungus is cultured in flasks, crocks, or shallow pits in the ground, using wheat and rice bran as the culture medium. *Beauveria bassiana* is applied as a granular or powdered product to piles of corn stalks and stubble collected in the fall to kill the overwintering larvae and to the tassels and silks of the summer crop. The control obtained was described as 83-96 percent for the overwintering larvae and 80-90 percent for the spring generation.[38]

Hungry ducklings, herded through rice fields in flocks of 1,000 or more, voraciously consume a variety of rice pests. It has been found that a single duckling consumes about 200 insects per hour. (Photo: H. Beemer, Jr.)

Among other approaches, nuclear polyhedrosis viruses (NPV) are being developed for the control of such pests as tussock moth, the cotton leafworm, and cabbage caterpillars.

Light Traps

Insect forecasting and control in China involves the use of light traps on a scale much greater than that in any other country. In Hunan province there are said to be about one million "blacklight" traps in an area of about 210,500 km^2. Networks of electric power lines intersect the rice fields. At night the eerie blue-violet glow of numerous blacklight traps was visible from the train traveling between Changsha and Guangzhou. The spacing of these blacklight traps varies from one trap per 1 to 2 ha in Jiangsu province, one trap per 2 to 3 ha in Guangdong province, and one trap per 3 to 4 ha in Hunan province.

A variety of traps were seen; all consisted of a 20-watt fluorescent tube emitting a continuous spectrum of light from 300 to 500 nanometers (nm), but with peak emission at 365 nm.[39] The fluorescent tube is centered between four vanes of glass, and the whole apparatus is commonly mounted over a permanent brick water basin or bucket. The water basin usually contains sticky rice water to trap the stunned insects, and the nutritious gruel thus obtained is fed to fish or hogs. For forecasting, electric grids or cyanide jars were used as the killing device beneath the fluorescent tube.

The development of these blacklight traps was apparently the result of careful study of the response of night-flying lepidoptera to monochromatic light. Ting et al. studied the phototactic response of cotton bollworms to 13 monochromatic lights ranging from 333 to 656 nm.[40] The 333-nm light was most attractive to the bollworms, but armyworm adults responded best to 375 nm. At the Nantong Institute of Agriculture, the attractive power of 20-watt blacklight traps and 200-watt incandescent traps was evaluated. During 1973 a combination of the two light sources caught 63,097 destructive insects compared with 11,035 by the blacklight alone.[41]

Insecticides

The origin of the use of indigenous Chinese plants containing insecticidal constituents is lost in the mists of 5,000 years. However, their use was extensive in pre-Revolutionary China and continues

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Intensive ecological study has led to complete abandonment of broad-spectrum insecticides such as DDT in Chinese agriculture. There is now almost no aerial spraying. The Chinese are currently attempting to develop procedures for the use of pesticides within a sound ecological framework. (Photo: H. Beemer, Jr.)

to be substantial today. In 1958 over 500 native plant and mineral products were processed into more than 10 million tons of insecticides and fungicides.[42] Among the principal products derived from native plants were alkaloids such as nicotine from *Nicotiana* species, anabasine from *Anabasis aphylla*, rotenoids from *Derris* species, and extractives from *Kalanchoe* (effective against aphids) and garlic. Research in this area is still continuing, and in conjunction with the renewed interest in Chinese medicinal plants, useful discoveries may be made.[43]

Following World War II, the worldwide publicity given to organochlorine insecticides, such as DDT, BHC, and other new synthetic organic insecticides, had an immense impact on pest control in China. Domestic production of DDT and BHC began after 1949, and about 60 million kg of BHC and 4.3 million kg of DDT were produced in 1958. The introduction of BHC was especially rapid and increased by 11,000 percent between 1952 and 1958. It was used throughout China for the control of major pests. Airplane applications were widely used for control of the migratory locust; between 1954 and 1958 more than 5.0 million ha of crops were saved from locust outbreaks in this way.[44]

At first this widespread use of the organochlorines was widely acclaimed. In 1963, Tsien-hsi Cheng said that "the mass production and wide application of BHC is a milestone in the history of Chinese agriculture." However, further usage in China produced the same series of problems as found elsewhere in the world—widespread insect pest resistance, development of secondary pests into major pest problems, and environmental pollution. By 1975 the use of BHC and DDT was rapidly being phased out and was no longer permitted on fruits and vegetables.[45]

Early in the 1950s a national decision was made not to produce the cyclodiene insecticides (aldrin, dieldrin, heptachlor, endrin, and chlordane) for agricultural use because of their long-term persistence and environmental toxicity. Small amounts of chlordane and mirex are still used for termite control in soil and timbers. Toxaphene is used in China in a limited way to control bollworms, but its use is forbidden near rice paddies and fish ponds because of its high toxicity to fish. The independent Chinese experience with the persistent organochlorine insecticides is particularly interesting in view of the controversy produced by their regulation and ban in many Western countries.

Organophosphorus insecticides are the basic synthetic insecticides in use in China, and more than 30 different compounds are produced commercially. The emphasis today is entirely on organophosphorus insecticides of low mammalian toxicity.

Trichlorfon, introduced in 1957, is apparently the insecticide produced on the largest scale in China today.[46] It is publicized as the "enemy of a hundred worms." Its popularity is due to its safety, lack of persistence, specificity against chewing pests, and environmental degradability. Trichlorfon is the main deterrent against chewing insects in IPM programs in cotton and rice, and on cabbage and other vegetables, and deciduous fruits. The order of production and use of organophosphorus insecticides has been described as trichlorfon, dichlorvos, dimethoate, phosmet, fenitrothion, phosphamidon, and malathion.[47]

Ecological Issues

Insecticide resistance has proved as vexatious in China as elsewhere. The housefly and numerous species of mosquitoes have become resistant to DDT and BHC, and to various organophosphorus insecticides, as have the fruit-tree red spider mite, the cotton aphid, the paddy borer, and the rice leafhopper.

Impressive efforts are being made to delay the onset of insect pest resistance by alternating insecticide treatments on apples and citrus: three to five different insecticides are used in rotation. Determinations of resistance and cross-resistance are given high priority. However, the prevailing scientific attitude about resistance is pessimistic, and the increase in the resistance problem is a major factor in encouraging pest management programs.

Experience in China with the widespread use of broad-spectrum insecticides has been generally unfavorable, partly because of the emergence of secondary pests. The experience with deciduous fruits has been typical. The early use of DDT gave good control of a wide variety of leaf rollers, but nearly eliminated the natural enemies of many pests, including red spider mites. The mites were controlled with parathion at first, but rapidly became resistant. The use of insecticides increased until they accounted for 25 percent of the production cost of the fruit. The leaf roller, *Leucoptera scitella*, became a

rampant secondary pest.

Intensive ecological study led to complete abandonment of broad-spectrum insecticides and to the development of a pest management program emphasizing: orchard sanitation; hand-picking of overwintering cocoons; interplanting orchards with legumes to encourage the ladybird beetle, *Coccinella septempunctata*, and other predators as well as the parasite *Aphytis proctia*; together with selective spraying using lime sulfur, trichlorfon, and chlordimeform.[49]

There is much concern in China about the overall effects of the intensive use of pesticides on human health and environmental quality. The use of such highly toxic insecticides as parathion and methyl parathion is very closely regulated, and handling is limited to highly trained and experienced personnel. The Ministry of Agriculture has established strict rules about application equipment, protective masks and clothing, and the availability of antidotes.

New insecticides that have adverse health and environmental properties must have governmental approval before use. An Institute of Environmental Protection was established in Beijing in 1978, and a national system of pesticide residue tolerances is being developed along with a system of restricted periods between application and harvest.

Insecticides play important roles in China's pest management programs, in its remarkable progress in producing food for more than one-fifth of the world's population, and in its exceptional standards of hygiene and public health. More than 100 individual insecticide compounds are produced commercially in China, and the government aims to become totally self-sufficient in this area.

The manifold disadvantages of the unrestricted use of broad-spectrum pesticides have been recognized, and efforts are being made to develop procedures for the judicious use of insecticides in a sound ecological framework. There is almost no aerial application of insecticides; selective treatment of hot spots of infestation in field or orchard is the general rule. Biological and cultural control measures are used wherever feasible, and supplemental insecticide controls are planned so as to be minimally disruptive to the total ecology of field, orchard, and forest.

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THE HUMAN COSTS OF DEVELOPMENT

BY JAMES RUSSELL McGOODWIN

ANTICIPATING THE CONCLUSION of the Third United Nations Conference on the Law of the Sea (UNCLOS III) in 1975, 80 coastal nations extended their jurisdictional claims over ocean economic resources to 200 nautical miles from their shores. Most of these countries are enthusiastically promoting new maritime developments, and in less developed countries (LDCs) the mood seems particularly bullish. Many of these nations—struggling with domestic food shortages and scarce capital for development—look to their fisheries as a source of protein-rich foods, and for substantial income from exports. However, before the LDCs surge ahead with the development of their fisheries, they need to consider the possible consequences of the strategies available to them, benefiting from the past experiences of other countries which have preceded them in fisheries development.

Timely lessons may be drawn from the fisheries-development experiences of Brazil, Thailand, and Japan; but the development of Mexico's shrimp industry on the Pacific coast provides a particularly instructive case.[1] The growth of its shrimp-export trade has been extraordinary, especially with regard to the income it has generated and the phenomenal quantities of capital it has accumulated. Crustaceans—not petroleum, cotton, sugar, or any other primary commodity—are Mexico's leading export item in terms of total value.[2] Today the state-instituted, urban-based industry boasts seven trawler fleets with more than 450 vessels; ten freezing, packing, and canning plants; two fisheries-research institutions; one shipyard; and two Mexican-owned importing corporations (chartered in the United States and located in San Diego, California). More than 94 percent of the industry's shrimp catch is exported—around 30,000 metric tons last year, which brought nearly $80 million in the international marketplace.[3]

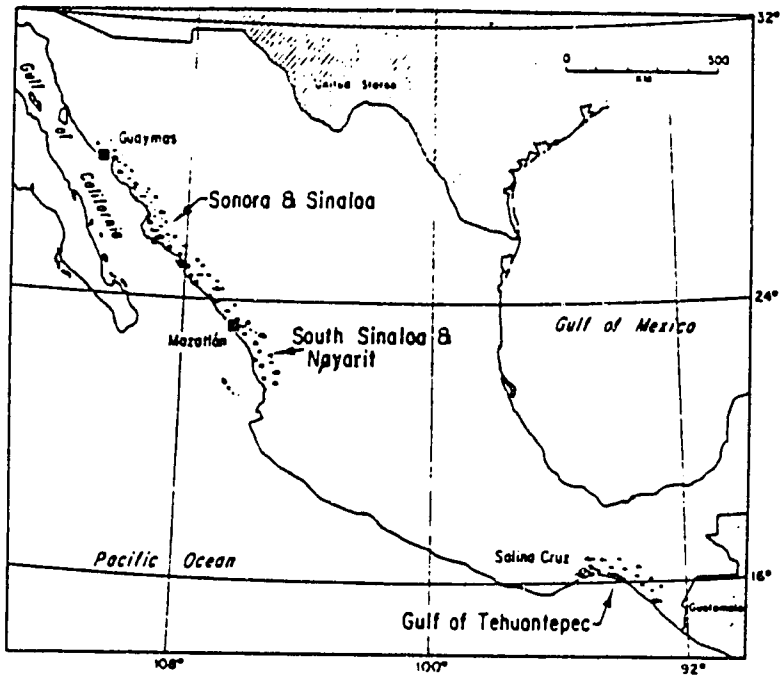
The growth of the shrimp industry has not been without its problems, especially those stemming from its dependency upon the United States, which is the major buyer of its production. But there is also a poignant and relatively unknown chapter in the story of its growth: the decline of the inshore fisheries and the corresponding impoverishment of thousands of rural-coastal peoples. By and large, the plight of these peoples is relatively unknown outside of the regions they inhabit. But their situation demonstrates how the development of one export industry—in this case Mexico's Pacific shrimp industry—can work unforeseen hardships in certain rural enclaves, and illustrates some of the larger problems created by the dependency of the LDCs upon the developed nations. Those involved in developing social and economic policy must become more aware of the ramifications created by the introduction of any new technology in a society.

South Sinaloa: A Case in Point

Coastal lagoons, salt marshes, and estuaries are important features of Mexico's

Pacific coast (see Map 1). These regions are the major inshore fisheries and the main rearing grounds for Mexico's commercially important species of shrimp. In former times they also produced great quantities of other seafoods, particularly oysters and fish.

Although this article focuses on the rural fisheries in the *municipio* [a legal unit similar to a U.S. county] of Escuinapa, south Sinaloa, the situation described for that region is duplicated to a greater or lesser extent in all of Pacific Mexico's rural-coastal fisheries. South Sinaloa is where today's shrimp-export industry had its beginnings, and in that region the social, economic, and political problems accompanying the growth of the industry have reached their point of greatest strain. Northward, among the lagoons and estuaries of Sonora, the rural population is relatively less dense, and southward, in the rural regions of the Gulf of Tehuantepec, the impact of the shrimp-export industry has been less severe. Nevertheless, living conditions in all of Pacific Mexico's rural-coastal regions are distressing.



MAP 1: Major Inshore Fisheries of Pacific Mexico.

In south Sinaloa average personal incomes of the region's household heads are less than $400 U.S. per year. Day-wage laborers in agriculture earn only about $2.50 U.S. per day when employed. Only 0.3 percent of the population has professional or technical training, and in the rural settlements less than two years of primary school is the mean educational level.

Most dwellings are crowded, squalid, and barren within, lacking sanitary facilities and running water. Fresh drinking water is always in short supply, and health and nutritional levels are extremely low. Infant mortality rates, moreover, are rising for the first time in decades, and the entire population is plagued by a variety of severe diseases—pervasive gastro-enteritis, amebiasis, and hepatitis, for example, as well as outbreaks of polio, tuberculosis, and rabies. In these hot and humid lowlands biting insects are also a problem.[4]

By and large, south Sinaloa's rural population owns or has access to very little productive land, so that the majority are dependent on whatever wages they can earn. More significant, however, is the fact that, in this region of extremely productive fisheries, food is often in short supply and much of the population suffers some form of nutritional disease. Only 2 percent of the total population are members of the government-instituted inshore fishing cooperatives, while the rest find their fishing activities severely constrained by laws reserving marine resources for the cooperatives.

The region's cooperatives, on the other hand, annually produce about 700 metric tons of shrimp—enough to provide every man, woman, and child with roughly 23 kilograms (more than 50 pounds) of that protein-rich food—but nearly 100 percent of that production is exported. And even the *cooperativistas* (members of the fishing cooperative), who have permission to harvest the region's seafoods, earn slightly under $700 U.S. per year.[5] Why, one wonders, are conditions so bad in these regions—the richest inshore fisheries of Pacific Mexico?

South Sinaloa's Coastal History

South Sinaloa's inshore fisheries were not always underdeveloped, nor were their human inhabitants as cut off from marine resources as they are today. Indeed, people have relied upon this region's rich coastal resources for at least 8,000 years, perhaps longer, and evidence of a considerable and long-term maritime history is clearly apparent to even a casual observer.[6]

The whole coastal region contains numerous shell mounds, some more than 3 kilometers long and 180 meters wide, with peaks reaching 11 meters. Not far from Escuinapa, head town of the *municipio* by that same name, archeologists have recently discovered a particularly large shell mound—a proto-pyramid, perhaps—21 meters high, quadrilateral in shape, and flat on top. Radiocarbon dating indicates that this structure was built about 2,000 years ago, suggesting the existence of coastal chiefdoms, and perhaps even nascent states, which subsisted upon the region's seafoods 16 centuries before the arrival of the Spanish conquerors.[7]

Estimates of the pre-Colombian population vary and are speculative, but some historians suggest that a relatively dense population inhabited the coastal plain at the time of the Conquest in the early 16th century.[8] Apparently, the Conquest-era aboriginal population was part of the Mesoamerican culture tradition, the same

OPPOSITE: Because rural houses around Teacapán, south Sinaloa, lack modern sanitary facilities, the inhabitants suffer a high incidence of nutritional, infectious, and parasitic diseases.

as the Aztec and Maya. They built platform mounds and ball courts on the higher ground behind the coastal zone; they decorated their pottery in the Mesoamerican style; they grew corn, beans, and squash along the river courses; and they harvested and traded great quantities of seafoods from the estuaries and lagoons.

The conquest of south Sinaloa brought about the destruction of the aboriginal population. The Indians were victims of diseases introduced by the Spaniards, and their ranks were further reduced by a number of factors which were either non-existent, or at least not as severe, in other parts of Conquest-era Mexico. They had the misfortune of being conquered initially by Nuño de Guzmán, one of the era's most genocidal *conquistadores*. Soon thereafter, many were taken as slaves for the mines in the Sierra Madre Occidental, and for Cuba's sugar plantations. The scattered few who remained were pushed out of the region, displaced by the lords of cattle-raising *haciendas* which became common in this region. Indeed, the region was effectively depopulated of indigenous peoples by the 1750s, and today none inhabit the coastal zone.

For nearly three centuries thereafter the region was almost empty of human inhabitants, and its abundant marine resources went unexploited. Then, in the early to middle 19th century, a trickle of new settlers arrived—*mestizo* immigrants from other parts of Mexico. They settled the coastal lands that became available following Mexico's independence from Spain in 1821. Still more immigrants came after the French occupation in 1867.

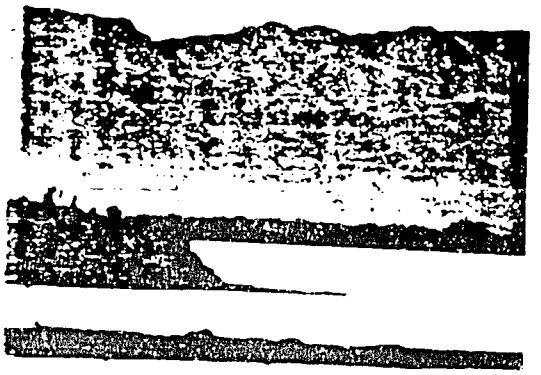
These new arrivals were quick to recognize the potential of the region's marine resources for subsistence and for commerce, and soon south Sinaloa's smoked oysters and salted shrimp were carried by muleteers across the Sierra to Durango and southward toward Guadalajara and Mexico City.

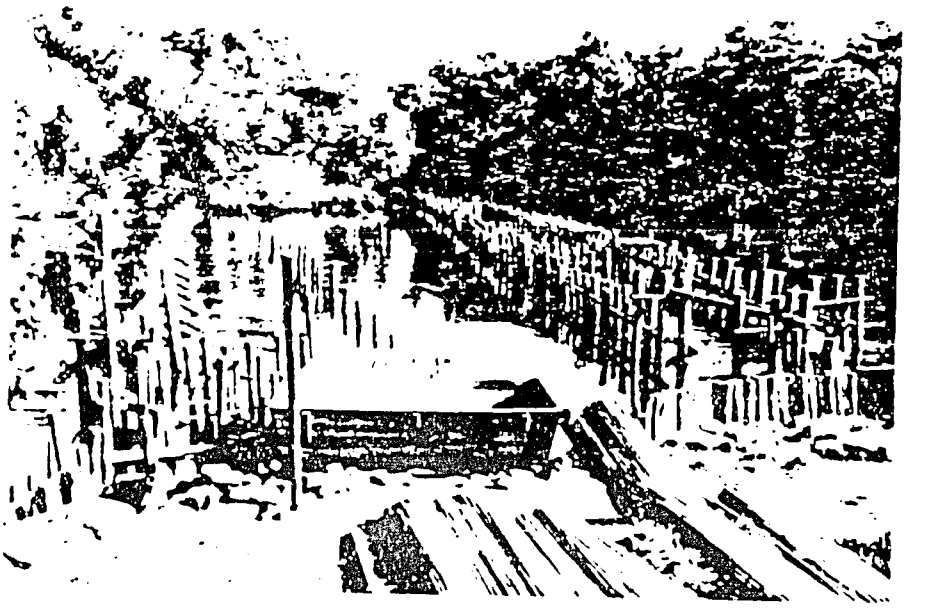
The landmark event for these fisheries occurred in the early 1870s when Chinese immigrants from Mazatlán visited the region around Escuinapa, bought large quantities of shrimp and oysters, and began to sell these to buyers from the United States, China, and Japan. In this manner, south Sinaloa's inshore fisheries made their debut in the international marketplace.[9]

By the outbreak of the Revolution in 1910, serious conflicts had arisen over the region's marine resources. The Diaz administration granted exclusive fishing rights to a number of small companies and limited subsistence fishing to regional fishermen not employed by the companies. During the Revolution, the brief Madero administration declared that subsistence fishing activities would be "free," and not subject to regulation.[10]

Today subsistence fishermen are still identified as *pescadores libres*, but now the term has a pejorative, criminal connotation, especially among fishing-industry officials, who use the term to refer to fishermen who are not members of the state-sanctioned rural-fishing cooperatives. Theoretically, subsistence fishing is still "free," but in actual practice it is greatly encumbered by various regulations that forbid shrimp harvesting for much of the year, or that prohibit such fishing in territories exclusively reserved for the cooperatives.

By the end of the Revolution, vessels from Japan and the United States were actively shrimp trawling along Mexico's Pacific coast. Mexico was powerless to prevent such incursions at that time: moreover, it lacked sufficient capital to finance the construction of its own vessels. Instead, it attempted to regulate and tax the foreigners fishing offshore,





This weir (called a *tapo*), which belongs to an inshore fishing cooperative on the El Mezcal estuary, south Sinaloa, is not in production. Its fencing has been rolled up and placed on the shore (foreground) so it will not rot. Rudimentary weirs such as these were the main technological items facilitating the beginnings of Mexico's Pacific shrimp industry in the 1930s.

"Pescadores libres"—subsistence fishermen.

while developing its own shrimp-export industry in its inshore fisheries.

Offshore, the Japanese eventually gained pre-eminence in the international shrimp market and drove their competitors from Mexico's Pacific coast by the middle 1930s. However, on the eve of World War II in 1939, fearing for the safety of its vessels so far from home, Japan abruptly withdrew its fleets from the area. Now at last Mexico had decisive control over all of its Pacific shrimp fisheries, and at this juncture it began to develop its own offshore fleets.

The Cooperatives

Mexico had already developed a system of state-instituted, inshore fishing cooperatives and central packing plants. Shortly after the Revolution, the Pacific's lagoonal and estuarial regions were declared federal territories. Then, with passage of the *Ley General de Cooperativas* in 1933, the nation undertook development of the various "enterprises of State participation" which characterize its Pacific fishing industry today.[11] Producers' cooperatives were established in the rural areas, along with a number of central packing plants for export operations. The rural fishing cooperatives of south Sinaloa and the packing plant at Escuinapa were the first of their kind on the Pacific coast.

Nearly all of the capital committed for the development of these enterprises went toward the construction of the regional packing plants. Development of the inshore fishing cooperatives involved little more than granting exclusive fishing territories and the recruitment of rural fishermen. The rural cooperatives required only rudimentary and fairly inexpensive weirs, which were constructed of mangrove posts and erected across tidal channels.

The rural cooperatives were inextricably bound to the regional packing plants by the terms of their charters. They were required to turn over all their exportable production to these plants, and to accept payment at whatever price levels the federal government annually established. Only in the conduct of their own internal affairs were they allowed to act as autonomous entities. Initially, this was not a handicap to the rural *cooperativistas*: marine resources were plentiful, the new organizations accepted nearly all rural fishermen wishing to join, and prices were such that most fishermen greatly increased their incomes.

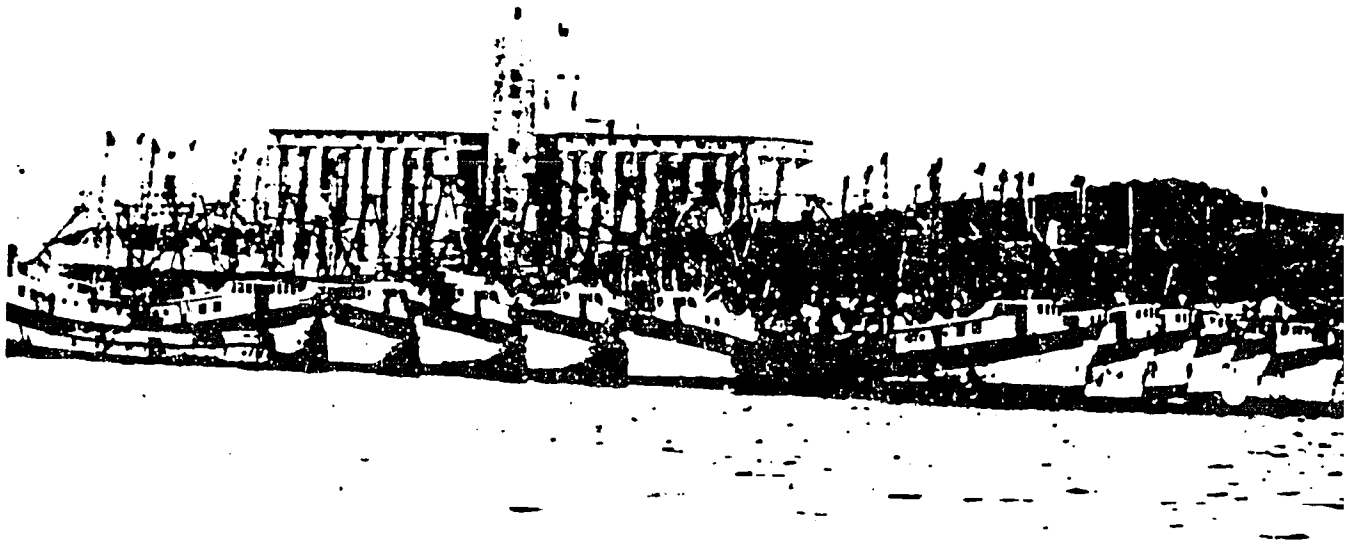
This was also the era of the establishment of the nation's agrarian *ejidos*,* and the rural fishing cooperatives were similarly hailed as important socio-economic reforms. Proponents claimed they would raise the standard of living of rural-coastal inhabitants and encourage wide participation in the fishing industry, and that the entire nation would benefit through the production of vitally needed foodstuffs and the generation of export income. In retrospect, however, it seems that the generation of export income was the main reason they were founded, for the other reform-oriented goals have eroded.

Social and Technological Problems

As economic entities, the rural cooperatives were fairly successful from the time of their inception through the middle 1960s, when Mexico's offshore shrimp-trawling industry finally overshadowed them. But long before that they had begun to suffer from serious problems.

Probably the most serious early problem was *caciquismo* (a corrupt, politi-

* Lands distributed to rural peasants as part of Mexico's post-revolutionary programs of land reform. Such lands are communally owned by a rural community; specific plots are assigned for an individual's use at no charge so long as he works the plot.



Shrimp trawlers with processing facilities in background, Guaymas, Sonora.

cal-economic bossism). During the Alemán administration, 1946-1952, *caciquismo* became widespread in the cooperatives, and it is still a problem in south Sinaloa. In many cases corrupt businessmen-politicians undertook to run the cooperatives for their own personal gain, relegating the *cooperativistas* to the status of mere shift laborers and denying them participation in the cooperatives' internal affairs—a right guaranteed in the organizations' charters. During that same period analogous situations arose on the nation's *ejidos*, particularly those producing export items.[12]

Other serious problems surfaced. The federal government periodically appropriated lands and redistributed these to impoverished peasants (*campesinos*)—resettling many of these into Sinaloa from other parts of the nation. South Sinaloa's rural-coastal population boomed, growing from around 8,000 persons in 1935 to nearly 31,000 in 1970.[13] As a result, competition for local marine resources intensified. Eventually the rural fishing cooperatives became entrenched economic entities, serving only a minority of the rural-coastal population. Internally, the cooperative also suffered from the effects of population growth, since membership rights could be inherited by members' descendants. Today south Sinaloa's cooperatives have more members than they need, and incomes must be shared with many marginally productive members.

Thus, by the early 1950s, south Sinaloa's rural-coastal population began to suffer serious strains, and the situation was greatly aggravated by the introduction of outboard motors and nylon nets into the fishery at that time. The use of outboard motors with large dugout canoes eased the transport of very large nets, while the nylon nets themselves, because they are nearly invisible underwater, proved disastrously effective in catching fish.

By that time most of the region's shrimp and oyster production was being sent abroad, so the fish which existed in great abundance in the estuaries and lagoons—snappers, snooks, drumfishes, mullets, and so forth—became the new mainstays of domestic consumption. However, the nylon nets quickly ravaged the inshore fish stocks, reducing them to very low levels within only a few years. Rural fishermen speak of former times, before the introduction of the motors and nets, when the surface waters of the lagoons sometimes appeared red from the shoals of snappers congregated there. Continued fishing pressure prevents the recovery of these resources, and today's net fishermen rely upon secondary species—so-called trash fish—which are converted into fish meal, a high-protein dietary supplement for poultry and livestock.

Why was the drastic over-harvesting of these prodigious fish stocks not prevented by the federal government, since it is empowered to regulate these fisheries? One reason may be that the fish, however important as domestic foodstuffs, were the major predators upon the region's shrimp stocks.

Other factors also contributed to the rapid decline of south Sinaloa's fisheries. Natural catastrophes, for instance, have played a part. In 1967 during the fall rainy season, a particularly severe flood buried the region's oyster beds under tons of silt, causing an almost total loss of that resource. Such floods have happened before in the region, at times with devastating consequences. Another flood in about 1300 A.D. similarly destroyed the region's oyster beds, forcing the partial abandonment of the fishery for a number of years thereafter.[14] Following the flood in 1967, the federal government imposed a moratorium on oyster harvesting and attempted to reestablish the beds; but its efforts have been only partly successful because the reduced oyster stocks have been subject to heavy pressure by rural *campesinos*, who illegally harvest them in order to provide food for their families. The oysters have also been damaged by contaminants—chemical pesticides mostly—used in the region's agricultural sector.

Offshore Trawling

Overshadowing all these disasters, however, has been the government's development of offshore trawling. The

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development of the trawling industry has brought about a parallel underdevelopment of the inshore fisheries. To understand why, it is necessary to comprehend the life cycle of Pacific Mexico's commercially important species of shrimp, all members of the *Penaeid* family.

In simplest terms, the shrimp are hatched from fertilized eggs in the open sea, and then, in the form of microscopically small larvae, they migrate up coastal estuaries and into briny lagoons. In those delicate environments they spend some months, growing to what would be recognizable as juvenile shrimps. Finally, they migrate back to the sea, reach their maximal size, and eventually spawn, thus completing their life cycle.[15] Their seaward migration is particularly intense during the fall rainy season, when the influx of fresh water greatly reduces the salinity of the lagoons, and it is this movement on which inshore fishermen have relied for millennia.

From the perspective of Mexico's offshore shrimp-exporting sector and the marine biologists and fisheries managers who advise it, harvesting shrimp while they inhabit the inshore waters is regarded as poor practice. Inshore harvesting takes the shrimp out of the ecosystem before they have a chance to spawn, which threatens the ability of the resource to recover rapidly. Also, by removing the shrimp before they reach adult size, the ecosystem's maximum potential shrimp biomass is not produced. Furthermore, the large adult shrimp caught offshore bring higher prices per unit of weight in the international marketplace. Finally, harvesting shrimp with trawlers is less costly and far more productive than the low-yield, labor-intensive methods employed by inshore fishermen.[16]

Thus, as Mexico pursued the development of shrimp-export trade in this century, it progressively curtailed the inshore shrimp harvest, dissociating the rural population from a resource that had been central to their subsistence and commerce.

Production figures for 1950-1970 for the Pacific's offshore sector and also for south Sinaloa's major inshore cooperative indicate the dramatic increase in offshore production and the correspondingly dramatic decrease in production inshore (see Figure 1). Today the government permits south Sinaloa's rural cooperatives to harvest shrimp for only 10 to 12 weeks per year, whereas the voracious offshore trawlers are allowed 35 to 40 weeks of production annually.

Other factors are indicative of the stressful quality of life in this rural-coastal zone. Ongoing conflicts among landowners, landless *campesinos*, and *ejidatarios* (small-scale farmers who work on *ejido* lands) occasionally prompt group actions and violence similar to the highly publicized incidents which occurred in northern Sinaloa around the time of the last presidential succession. Severe conflicts also exist over rights to regional marine resources. *Campesinos* in the rural settlements sometimes shoot at the cooperatives' trucks—especially at night—as the vehicles pass through the countryside on their journeys between the lagoonal weirs and the packing plant. *Campesinos* engaged in subsistence fishing are sometimes arrested by soldiers from the *Infantería Marina* (the Mexican Navy's infantry), who are deployed in the fisheries during the fall shrimp harvest to enforce the cooperative's exclusive rights. Such enforcement measures have been only partly successful, however, because of the rural fishermen's dispersion in the labyrinthian systems of estuaries and lagoons. A few large-scale shrimp contrabanders also seem to operate with relative impunity, perhaps buying their security.

South Sinaloa's rural fishermen are not ignorant of the events which have marginalized their traditional way of life. Often, in the context of discussions concerning the development of offshore trawling, they exclaim, "*Camarón que duerme se la lleva la marea*" ("A shrimp that sleeps is taken by the tide"). The statement is an ironic, self-conscious acknowledgement of their socio-political dormancy as well as their inability to stem the tide of events which has impoverished them.

Current Policy

It would be glib to conclude that the negative consequences of developing Pacific Mexico's shrimp-export industry could have been easily avoided. Hindsight is always clearer than foresight. When today's shrimp-export industry was first organized, the nation was badly in need of capital to finance its reconstruction, and, at least initially, the inshore fishing cooperatives did elevate the standard of living in the rural-coastal areas. In 1933 the post-Revolutionary leaders could not have foreseen the great population growth to come and, given the nation's preoccupation with its agricultural sector and a lack of interest in the cultural traditions of the inshore fishermen, these reformers should not be blamed for emphasizing the development of shrimp exports.

But Mexico is now experiencing acute and widespread food shortages, rising infant mortality rates, and an exodus of its rural poor to its crowded cities and to the United States.[17] Nevertheless, the federal government continues to announce plans to further develop its shrimp-export industry, despite increasing evidence that the industry has already reached the limits of its growth. Shrimp stocks have been declining for a number of years.[18] Some industry entrepreneurs question the evidence, pointing out steady production increases over the past decade; but the industry's own fisheries biologists counter that such increases only reflect the annual addition of new trawlers to the fleets. Various methods for increasing shrimp stocks are still being tried. The most important involves dredging projects which would facilitate the shrimp migrations between offshore and inshore waters; but these do not promise to make a significant difference over the long run.

Furthermore, since the industry exports nearly all of its production, its dependency upon the international market—and especially the United States, its major customer—often places it in a precarious economic position. In 1971, for example, the United States' unilateral imposition of a 10 percent surcharge on import tariffs precipitated an economic crisis having painful ramifications throughout Mexico's shrimp industry. President Echeverría responded by courting other foreign buyers for Mexican shrimp, particularly the Japanese, promising he would "weaken the embrace of the North," but such actions were futile.[19] The United States is still the major purchaser of Mexico's shrimp exports, and the industry is still highly

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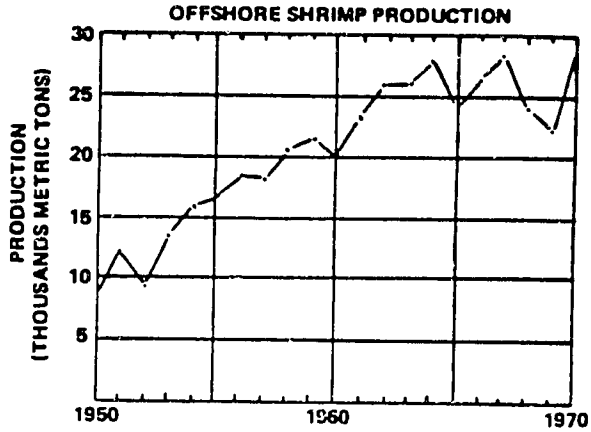
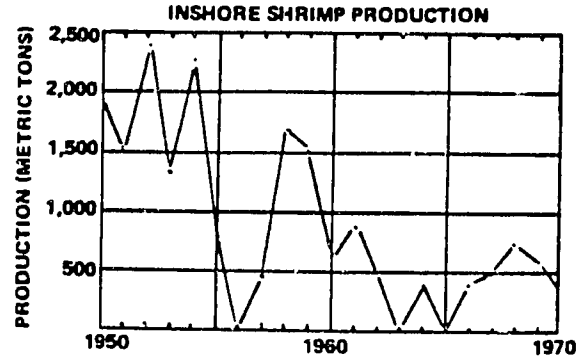
FIGURE 1. Shrimp production in Pacific Mexico, 1950-1970.



Annual offshore shrimp production for Mexico's Pacific coast. Offshore production rose almost 300 percent during the twenty years, 1950-1970. SOURCE: Instituto de Pesca, Mexico, D.F.



* Mexico imposed a moratorium on production in these years.

Annual shrimp production of south Sinaloa's major inshore fishing cooperative. Inshore shrimp production dropped from a high of 2,400 metric tons in 1952 to a low of 400 metric tons in 1970. SOURCE: Mendoza von Borstel, Xavier, Mem. IV. Congr. Nac. Oceanografia (Mexico): 407-418, 1972.

vulnerable to the vagaries of the international marketplace.

Dependency upon the international market has also caused the industry to engage in market behavior which seems indefensible for a nation experiencing food shortages. In spring 1978, for example, stories appeared in the nation's press reporting the destruction of large quantities of seafood in order to drive up its price in the international market. In the same period domestic food supplies were reported scarcer than ever. Those resources might instead have been distributed to ultimate consumers in food-deficient regions.

Mexico needs to seriously reconsider its policies for the management and development of its Pacific-coastal fisheries. It should stress revitalization of the inshore fisheries, encourage the resurgence of inshore fish stocks, and relax its restrictions upon individualistic subsistence fishermen and small-scale regional commerce. Positive steps should also be taken to invigorate the nation's domestic seafood markets.

Such a change of policy might not be as radical as it first seems. Indeed, it may come about naturally as increased exports of petroleum from the Campeche Bank appreciate the *peso*, thus reducing the relative profitability of shrimp exports. Perhaps then the nation will not have to rely as heavily as it has in the past upon the export of an important food commodity.

Few LDCs are fortunate enough to have huge undeveloped reserves of energy resources, but they—and those countries and international agencies which are assisting them—could learn much from the development of Mexico's shrimp-export industry. The Philippines, for example, has both rich shrimp resources and a large, traditional, rural-coastal fishing population, and that nation is now actively developing its fisheries. Having established a 200-mile offshore economic zone, the Philippines—like many other coastal LDCs—is being lured by the export income which certain seafoods promise. Unfortunately, many LDCs ignore the poverty of their rural-coastal regions, viewing that and the development of their fisheries as distinct, or unrelated, problems. Here the work of anthropologists, ethnohistorians, rural sociologists, and economists could inform the course of these nations' future fisheries' development.[20]

Fishing is a small part of the GNP in most countries. Even in Japan, a nation well known for its extensive fisheries and fishing traditions, the value of agricultural output exceeds that of fishing by 50 times.[21] As a result of its relatively small role in most nations, fisheries are often not well understood as a socio-economic phenomenon. This may lead national economic planners to lump various forms of fishing under one rubric, so that they fail to distinguish crucial differences between subsistence versus commercial fishing, or inshore versus offshore fishing. Moreover, many nations may not be sufficiently aware—because they lack the appropriate information—that increased income from fisheries' exports may, in some cases, be more than offset by the consequent social and economic costs in their rural-coastal zones.

These considerations, as well as the undesirability of economic dependence on foreign markets, suggest that LDCs should exercise great caution when planning to develop fishing industries predicated on the production of income from exports. Moreover, the participation of their own rural poor in fisheries development should, as a matter of policy, be given at least equal importance with the possible income the fisheries can generate.

NOTES

1. See James Russell McGoodwin, Fisheries Policy and the Underdevelopment of Inshore Pacific Mexico, Woods Hole Oceanographic Institution, Technical Report 79-44, 1979, p. 6; also, by the same author, "The Decline of Mexico's Pacific Inshore Fisheries," Oceanus 22 (1979): 52.

2. Food and Agriculture Organization, Trade Yearbook 1972, FAO, Rome, 1972: United Nations, Economic Survey of Latin America 1972, U.N., New York, 1972.

3. Centro de Estudios Políticos Económicos y Sociales, Síntesis Estatal 196 1978, and Jornades de Información y Estudio para la Programemación del Desarollo de Sinaloa 1968-1978, Centro de Estudios Políticos Económicos y Sociales, Culiacán, Sinaloa, 1968-1978 (annual reports).

4. Manuel Casas Pérez and Gabriel Rodriquez Salgado, Estudio para el Financiamiento Agropecuario en la Zona Sur de Sinaloa, Banco Agropecuario, Mexico, D. F., 1967.

5. Note 3 above.

6. Carl I. Hubbs and Gunnar I. Roden, "Oceanography and Marine Life Along the Pacific Coast of Middle America," in Robert C. West, ed., Handbook of Middle American Indians, Volume 1, Univ. of Texas Press, Austin, 1964.

(continued on page 42)

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Sociological Perspectives on Energy and Rural Development: A Review of Major Frameworks for Research on Developing Countries[1]

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ABSTRACT The contemporary energy situation raises new problems for rural development which require fresh thinking and perhaps some reorientation by sociologists. Five major frameworks for the sociological analysis of energy-rural development interactions in developing countries are critically evaluated. The frameworks are appraised in terms of their conceptualization of energy and its social significance, and the sociological variables emphasized. It is argued that despite the relative unfamiliarity of energy to many sociologists, an uncritical acceptance of the models, concepts, and assumptions of technological perspectives on energy is unwarranted. Energy reductionism, in particular, is a technological imperative that can have a very significant impact on the characteristics of sociological analysis.

Introduction

Broader awareness of the energy trap to which most societies have become vulnerable has peaked in recent years for obvious reasons. Among industrial societies, dramatic escalations in prices, shortages in supplies of hydrocarbon products, and heightened concern for the exhaustibility of improperly-managed natural resources have combined to create a sense of "crisis" in some sectors. While work on the American food system has pointed to its high energy intensity (Buttel and Larson, 1979; Desai, 1977; Pimentel *et al.*, 1973; Steinhart and Steinhart, 1974) and recent agenda for basic agricultural research reflect sensitivity to petroleum dependence problems (National Academy of Sciences, 1977; Oyer, 1976; Wittwer, 1978), other research has suggested that in biomass productivity terms the American agricultural system is highly efficient (Pasour and Bullock, 1977; Revelle, 1979) and that agricultural energy problems are not serious because agricultural production represents only 3 percent of the nation's energy bill. Less affluent countries are much closer to the margin in meeting even basic human needs for significant proportions of their populations. They are much more heavily reliant on agriculture to generate income and employment in rural areas and to satisfy the

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often competing requirements for food and foreign exchange (Lappe and Collins, 1977). In these countries, the energy crisis is less a shock than another step down a blind alley. Over a generation, strategies to improve agricultural productivity and develop viable modes of non-agricultural rural employment have barely kept pace with population growth (Asian Development Bank, 1977). Furthermore, efforts to increase food production using high input cultivation regimes have revealed the land-energy trade-off which this usually involves—diminishing returns in protein per hectare year to intensified input applications (Slesser, 1973; Slesser *et al.*, 1977). In recent years, it has become clearer that the technological and institutional prerequisites of these developmental strategies may only be sustainable at increasingly higher cost in terms of resource requirements, regressive social impacts, and future inability to adapt (International Labor Organization, 1978; Koppel, 1978).

For many countries, a range of very complex energy policy questions are in varying stages of engagement (Resource Systems Institute, 1978). Most of those questions are beyond the scope of this paper, but a general awareness of their content will be assumed. What will be discussed here is the following issue: What frameworks should sociologists be using to understand the energy-rural development interface, especially in developing countries? The question is hardly academic. Rural sociologists will be asked to participate in judging the feasibility, appropriateness, and impact of various rural energy strategies in developing countries. The impetus will come from the Board for International Food and Agricultural Development (BIFAD) institutional strengthening grants, the Title XII program, strong interests within the Agency for International Development (AID) and emerging programs in the United States Department of Agriculture, just to name a few. Our purpose is to stimulate discussion which confronts many of the crucial uncertainties surrounding the social significance of energy issues.

The problem is stating the problem

Determining an appropriate analytical framework is a decision which reflects the central vision of the problem to be analyzed. If we review work accomplished to date on energy and rural development, the outlines of several visions can be discerned. Before discussing these in any detail, however, it will be useful to identify some common attributes of existing work on developing countries. The following critical conclusions can be drawn:

(1) *The work is overwhelmingly energy assessment.* The evaluation of specific technologies or tasks in net energy terms is carried out within the framework of a distinct "rural energy system." The utility of

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"rural energy system" as a meaningful metaphor has not been evaluated. One consequence is that research is only occasionally oriented to contemporary agricultural development issues or to a broader conception of rural development.

(2) *Existing research has relied extensively on the aggregation of energy coefficients across a wide range of tasks and users.* This is a result, in part, of data constraints and can be considered a measurement problem. There are still very few carefully-executed household energy demand studies for low income families in rural areas, and there is considerable variation in the ways national energy statistics are generated, treated, and published.

A measurement problem, however, is often symptomatic of a basic conceptual problem. The focus on aggregation illustrates a measurement problem which follows from inadequate attention to the issue of energy indexing. It is commonly assumed in energy analysis that all kilocalories are equal. The assumption may be acceptable where only a single fuel is being measured, but when the analysis includes different types of fuels, as well as fuel production and consumption systems, the assumption is false and the comparisons of energy quantities misleading. The difficulty arises from the differences between work potential and work performed, an efficiency issue derived from the second law of thermodynamics. For example, one Kwh of electricity has far greater work potential than one Kwh (thermal) of coal. Does it follow that one Kwh of electricity represents "more" energy than one Kwh (thermal) of coal? Not necessarily. It might take three times as much energy resource to deliver one Kwh of electricity as it does to deliver a Kwh (thermal) of coal. "Like money, one does not expect a single number to tell one everything one needs to know" (Slesser, 1978).

Nevertheless, there is strong interest in developing a common metric based on some understanding about energy quality. An effort to reach such an understanding is problematic in part because thermodynamic limits on many energy conversion processes commonly used in rural areas have not been established. It is made even more complex by the linkage of the energy quality issue to institutional, economic, and even cultural factors. The energy indexing problem is extremely basic, but it should not be foreign to those sociologists who have employed the tools of systems analysis nor to those who have examined the generally high correlations between commercial energy consumption and urbanization. What the aggregative emphasis has ignored, with only a few exceptions (Bealer, 1980; Harris, *et al.*, 1980), is that within the same society several energy quality systems may be operating and that there may be significant relationships between overall

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energy efficiency (not just commercial fuel consumption) and various modes of social organization.

(3) *That portion of existing research which is oriented to the consideration of policy options frames the choices, with few exceptions, as technological.* The technological imperative is evident in the principal social question normally raised: "What social changes are necessary to accomodate technological solutions to energy problems?" That type of question limits at the outset the alternatives which will be considered.

(4) *Rural sociologists and other social scientists concerned with rural development have taken, at best, only a minor role in conceiving, implementing, and analyzing rural energy research.* This situation reflects a basic institutional reality in most developing countries: It is not the rural development or agricultural research agencies that are in the rural energy policy arena; it is the recently created energy ministries that are engaging in explicit discussions of energy issues in rural areas.

Despite this rather unsatisfactory overall picture, several more positive aspects of existing research on energy and rural development can be noted. There is an increasing tendency to locate the rural energy question within the food-poverty syndrome (National Research Council of Thailand, 1979; Resource Systems Institute, 1979a, 1979b, 1980; Revelle, 1978; United Nations University, 1979). There also appears to be an emerging concern to moderate some of the more spectacular alarmist assumptions which have previously motivated much rural energy research. This moderating trend is characterized by more carefully-executed household and village studies, by occasionally specifying sociological variables as exogenous, and by giving more attention to the wide variation in rural energy mixes and rural energy end-uses (Bajracharya, 1980; Bhatia, 1977; Desai, 1978; Koppel, 1980; Makhijani and Poole, 1975; Smith *et al.*, 1980; Tyers and Revelle, 1978; Weingart, 1979b).

Our discussion now turns to a closer examination of the principal sociological frameworks which are represented, in one version or another, in existing work or, in our judgement, appear as strong candidates for utilization in future research. Our purpose is not to definitively introduce the frameworks to those unfamiliar with them nor to provide original interpretations of their characteristics for old hands. The purpose is much more limited, namely, to suggest what the frameworks have to say about energy. If our characterizations sometimes appear too general or tentative, it is because there are too few cases of clear application to support more categorical statements about how researchers using these frameworks are proceeding. In those cases, we are making appraisals based on likely attributes of framework application to rural energy questions.

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Socio-technical analysis

This framework, developed principally within industrial and organizational sociology, is oriented to the decomposition of technological processes into basic tasks or components. Analysis focuses on the relationships of organizational and managerial characteristics to attributes of tasks and technological processes. The framework's application to rural energy analysis has been accelerated by the early popularity of the "flow" metaphor as an approach to understanding energy-rural development interactions. Energy was seen as "flowing" through rural systems. In the socio-technical framework, however, energy flows do not necessarily occur in a system integrated around some factor other than energy. Research concentrates on chains of agricultural and household energy uses.

Socio-technical analysis can provide a basis for translating characteristics of technological processes into social terms. Examples include research on cooking functions (Institute for Energy Research, 1978), crop drying (Chancellor, 1978), rice production (Kuether and Duff, 1979), and biological pest control (Kenmore, 1979). Socio-technical analysis can also be a useful basis for comparing alternate ways of performing the same task—for example, biogas generation (Santerre and Smith, 1980; Smith and Santerre, 1980). The major limitation of socio-technical analysis is that the rural social milieu tends to be present only in the form elicited by technological components or energy "flows." A rural energy "system" is assumed to be a meaningful entity. This assumption yields a reductionist vision of a social system, one in which the system exists only within a line-item energy account. Beyond the order supplied by the reconstitution of energy conversions into some technological process, the social system does not really exist.

Evolutionary perspectives

This framework seeks to identify systematic processes underlying the distribution of technologies and patterns of technology utilization across geographic and social space as well as across time. Perhaps the most familiar example to rural sociologists is diffusion research. One approach has been to use a diffusion framework in forecasting. Marchetti and Nakicenovic (1978), for example, studied the time frame and adoption pattern for large-scale changes in technology systems as a basis for forecasting rates of change in energy systems. Others have used similar procedures to generate forecasts of large-scale conversions to decentralized solar thermal and photovoltaic electricity systems and widespread use of biogas and biomass related energy technologies (Buffington and Zar, 1977; Electric Power Research Institute, 1978; Prasithrathsint, 1979; Weingart, 1979a). Such studies are useful ways of thinking in specific terms about alternate futures. The major limitation of the approach for energy analysis stems from

a tendency to improperly generalize historical patterns of energy use and social change. Generalizations about renewable energy systems, for example, based on diffusion of non-renewable energy technologies often contain quite arbitrary assumptions about the variability of relative factor costs, risks, and externalities. The wise variation in basic estimates of coal and oil reserves, "proven" and "undiscovered," makes it difficult to properly characterize the diffusion characteristics of past patterns of energy resource depletion. For studies on rural areas of developing countries, attempts at extrapolation based on interpretations of agricultural technology diffusion studies may be premature. Agricultural technology diffusion studies have focused on the use of petrochemical inputs (such as nitrogenous fertilizer) and middle distillate products (such as kerosene). This gives an incomplete picture. What is missing is adequate attention to: (1) the complete fuel resource base available to and allocated by rural users, and (2) the complex intermediate roles played by technologies for fuel production and fuel consumption in linking energy sources and end-uses.

Another evolutionary perspective on the energy-rural development problem is a continuing tradition of anthropological and rural sociological research which can be broadly placed within the framework of White's energy and cultural development hypothesis (Adams, 1975; Buttel, 1977; Buttel and Larson, 1979; Cottrell, 1955; Shiels, 1972; Spicer, 1952; White, 1943, 1959). White's thesis basically posits a monotonic relationship between cultural complexity and aggregate energy consumption. Energy is assumed to be a critical limiting factor for cultural adaptation. White's (1959) thesis has motivated considerable research. Recent empirical work by Rambo (1979a, 1979b) refutes the linear hypothesis for *per capita* energy consumption. Further re-evaluation of White's hypothesis should yield interesting research on the relationships between changes in social scale and complexity and patterns and intensity of energy use. A major problem, however, for this version of evolutionary research is the misleading and possibly noncomparable indices that result from aggregating a wide range of energy uses and fuel types in terms of a single heat measure. The issue is the problem of energy indexing, which was discussed earlier. Energy indexing is not simply a measurement problem but a conceptual problem: what is energy? Analysis in the White tradition will need to find ways to resolve or circumvent the energy indexing problem.

Evolutionary research can be useful as an approach to comparative analysis and as a basis for stating and verifying a limited set of basic energy-social organization typologies. The utility of the framework for rural energy research, however, ultimately rests on the vision of "what" is evolving and "what" if anything is being replaced, modified, or recast. It follows that as there is clarification of what it is about

for each factor. One way of initiating such an evaluation is to choose an arbitrary value, say 100, for the suitability of a certain type (e.g., Drummer-Flannagan soil) of a certain factor (soils) for a certain land use (e.g., row crop agriculture). All other evaluations are then made with reference to this standard, using the unit implied. The dollar is one unit of valuation that people are used to applying to a wide, but still limited, range of options. Therefore, another useful evaluation procedure is to express suitabilities by factor directly in estimated dollar units (Hopkins 1975).

Although some people do not believe that such all-inclusive ratings can exist, the same thing is being accomplished through the weights in the usual linear combination method. The protection of not understanding exactly what the ultimate ratings will be has simply been removed. Freeman (1970) has provided a straightforward explanation of the necessity of valuation in making choices (see also Hopkins, et al. 1973). One can do the valuation explicitly or implicitly, but any choice among alternatives with respect to a set of factors implies a relative valuation of factors at least sufficient to make that choice.

Independence of factors. The linear combination method corrects the measurement problems of the ordinal combination method, but the problem of handling interdependence among the factors still remains. The linear combination method cannot deal with the situation where the relative suitability for a given land use of a type on one factor depends on the type on any of the other factors. Despite its inability to handle interdependence among the factors, the linear combination approach is still frequently used, as implied for example by the discussion of weighted overlays in Steinitz, Parker, and Jordan (1976). There are three possible justifications for continued use of the linear combination method.

First, the factors might be known to be independent because they had been derived through factor analysis or some similar statistical technique that generates independent factors. This possibility, and the need for independent factors as inputs to a cluster analysis of regions, was recognized in the Rice Center (1974) study. The researchers implemented it, however, only to the extent of using human judgment to identify independent factors. Durfee (1972) has discussed the potential for application of factor analysis, but it has not been applied to justify using a linear combination method in determining suitabilities. Limited experimental experience suggests that, because of the data requirements and difficulty of interpretation, using factor analysis to identify factors is not worthwhile for most suitability analyses.

The second possible justification is that linear combination, though highly imperfect, is the best method available in the sense that the benefits from any alternative method would not exceed the cost of applying that alternative. The rules of combination method described below can handle interdependence and requires no transformation to numerical values. Therefore, the linear combination method cannot be justified as the best available method.

The third possible justification is that the factors typically used such as bedrock geology, surface geology, ground water, surface water, soils, slope, vegetation, and existing land use can be deductively determined to be independent. Although examples of interdependence among these factors are harder to identify than some people might expect, there are many. Recall the above case of slope, subsurface, and soils. Another example would be adding the amenity for residential use of an existing tree canopy and subtracting the cost of artificial drainage required because of soil conditions. Installation of the artificial drainage and the resulting change in water table would eliminate the vegetation canopy. Therefore there is interdependence among the factors: the value of the vegetation type depends on the soil type.

Although interdependence among the frequently used factors does exist, not all factors are interdependent. In addition, some factors that affect several types of costs and impacts, such as soils, may be interdependent with respect to some of these costs or impacts but not others. It is certainly acceptable to use a linear combination for particular instances where it can be empirically or deductively shown to be correct. For example, costs for constructing a foundation to compensate for poor soil conditions are independent of the vegetation cover type. Therefore the construction costs could be subtracted from the vegetation amenity value.

The linear combination of factors should be viewed as a particular case. It is only one of an infinite number of possible functions for combining factors. The linear combination method can not be applied appropriately across the board to all combinations of factors. Of course, some factors are independent; but the point is that many land use suitability studies have used the linear combination method to apply to all factors, as if the method were inherently correct without regard to observable interdependence among factors.

Nonlinear combination method

Interdependence among the factors could be handled if the combination equation were not linear. If the appropriate relationships among the factors are known and can be expressed as mathematical functions, the nonlinear combination method is ideal. Instead of a linear combination (weighted addition) as in deriving step 4 in Figure 4, the ratings of types are plugged into the nonlinear functions and results are obtained analytically for all factors combined.

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The only difference from Figure 4 is that the combination equation to get from step 3 to step 4 contains a nonlinear relationship instead of addition. However, this method is not likely to be possible for studies of the kind under consideration, because the relationships required to deal with the full range of costs and impacts are not known.

Although Storie (1933) proposed a nonlinear (multiplicative) index of soil factors for agricultural production, he provided little convincing evidence for the functional form chosen. Voelker (1976) presented a rating index for site costs with a nonlinear relationship between percent coverage of vegetation and a previously computed index that is a function of soil and slope. He reported iterative, judgmental fitting of the index, but this is just one of many required relationships. The most frequently used nonlinear combination functions are the standard equations for computing runoff and soil loss for given combinations of types of land cover, slope, and watershed shape. Although these equations are certainly useful, they apply only to specific components of an overall suitability rating.

Most nonlinear equations that are widely used generate suitabilities regarding generation of impact, runoff for example, rather than suitabilities for land uses. As discussed at the beginning of this article, such impact suitability maps may be inputs to land suitability maps, but they constitute only one factor in the broader level of analysis that is required. The nonlinear combination method overcomes the problem of interdependence among factors, but so far it has not been operationally useful for generating overall land use suitabilities.

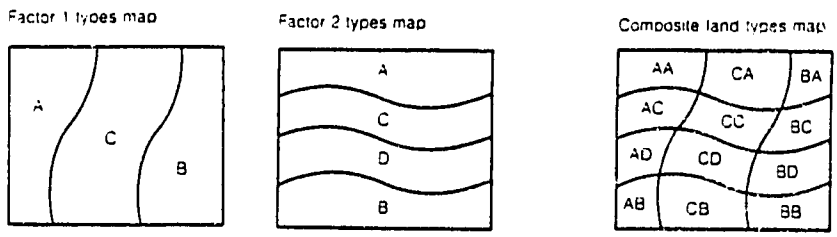
Explicit identification of regions

One way to avoid the problem of interdependence among the factors is to first identify homogeneous regions explicitly. The homogeneity of regions does not depend on the independence of factors. Given the homogeneous regions, the suitability ratings for each region can be determined by implicit judgment concerning the combinations of types that then define the regions.

Factor combination method

A straightforward modification of the gestalt method allows one to deal with interdependence among the factors but with a tremendous loss of efficiency compared to the methods described in the previous section. Figure 5 describes the same artificial problem

Figure 5. Factor combination method

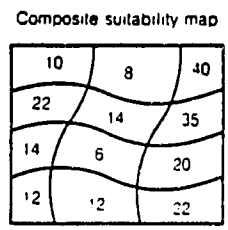


Step 1. map data factors by type

Step 2. intersect factor types maps to obtain composite

Regions	Land uses R1	R2	R3	R4
AA	10.0	•	•	•
AB	12.0	•	•	•
AC	22.0	•	•	•
AD	14.0	•	•	•
BA	40.0	•	•	•
BB	22.0	•	•	•
BC	35.0	•	•	•
BD	20.0	•	•	•
CA	8.0	•	•	•
CB	12.0	•	•	•
CC	14.0	•	•	•
CD	6.0	•	•	•

Step 3. rate each region for each land use



Step 4. map suitability ratings for each land use, one map for each land use

used for illustration previously, but in this case the order of steps 2 and 3 is reversed. Step 2 now consists of combining type maps for each of the factors to obtain a composite map of regions that are homogeneous with respect to all factors. No rating is implied; this map is merely a complete logical intersection or factor combination of the boundaries of the regions from each factor map. It is equivalent to a very complex Venn diagram in set theory.

Step 3 is now the derivation of the suitability ratings table. Instead of a list of factors and types for each, the vertical axis identifies all the regions that occur on the map. It is thus equivalent to the table for the gestalt method in Figure 1, except that an explicit procedure has been used for deriving the homogeneous regions from the individual factors. One can now evaluate the suitability for each land use relative to each specific combination of types, without having to consider the general relationships among individual factors as in the linear combination and nonlinear combination methods. It is evident that, just as in the gestalt method, implicit judgments are used to determine the suitabilities. The determination of homogeneous regions has been made explicit; the determination of suitabilities has not.

The *Plan for the Valleys* by Wallace-McHarg Associates (1964) is a simple example of this method. Two factors, forest cover and topography, were used to generate five combinations: valley floors, unforested valley walls, forested valley walls, forested plateau, and unforested plateau. By implication, forest cover did not apply to any valley floor areas on the site. Management principles were prescribed for each region (see also McHarg 1969, pp. 79ff.).

Factor combination is suitable for studies involving only a few factors; a larger number of factors makes infeasible the determination of suitability ratings for each combination. The most time consuming part of a real study is identifying the ratings to go into each box in the suitability table. It is thus desirable to minimize the number and difficulty of evaluations. Note that the table for the linear combination procedure in Figure 3 requires suitability ratings for various activities on each type within each factor. This number (seven in this example) equals the sum of the types over all factors for each activity. For the factor combination method, however, the table includes a row for each homogeneous region that actually occurs on the site. This number has an upper bound (twelve in this example) that is equal to the product of the number of types for each factor. The potential number of combinations is enormous—if one dealt with ten factors each having ten types, the number of possible homogeneous regions to be rated would be 10^{10} or one billion. For the same set of factors the table for the linear combination approach would require assigning ratings to only 100 types.

This tremendous difference in the required number of evaluations is reduced by mapping the homogeneous regions first. Most of the possible combinations will not occur on a real site due to spatial correlation among the ecological factors. In one unpublished study carried out in this fashion by the present author, approximately 5 percent of the possible combinations actually occurred. However, if accessibility relationships among existing and potential activities were one of the factors, this percentage would be much greater. Even with the potential reduction of regions by mapping to determine those that actually exist, the suitability table for the factor combination procedure may be unwieldly, especially for large, diverse study areas. The factor combination method has the further disadvantage that the rating of regions in terms of suitability relies entirely on implicit judgment for the transformation of the types in the combination into a rating for the combination as a whole.

Cluster analysis

Cluster analysis, used in the Rice Center (1974) study, also explicitly identifies homogeneous regions by successively pairing the most similar sites or groups of sites, based on an index of similarity across the set of factors. The process is stopped at some predetermined acceptable level of diversity within the clusters, resulting in a set of regions, each with a profile showing the range of types for each factor. As in the factor combination method, this profile still must be transformed into some aggregate rating by implicit judgment. The clustering does, however, serve to reduce explicitly the combinations of types to be considered.

One of the most interesting potentials of the cluster analysis method is the possibility of using the statistical measures of variation on factors within clusters as measures of suitability. Diversity within a homogeneous region is often a more useful measure of suitability for particular uses than a modal type or a specified range. For example, a region with diverse slopes makes a good site for a planned unit development; a region with all flat land or all steep slopes does not. However used, cluster analysis requires great care in interpretation and significant costs for computation. Cluster analysis can not be justified unless expected results are significantly better than from other methods; this case has not yet been demonstrated.

Suitabilities by logical combination

Rules of combination is a useful label for a class of methods that is, in a sense, a compromise between the nonlinear combination method and the factor combination method. The rules assign suitabilities to *sets*

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of combinations of types rather than to single combinations and are expressed in terms of verbal logic rather than in terms of numbers and arithmetic. It is then not necessary to evaluate each combination separately as in the factor combination method; nor is it necessary to find a precise mathematical statement of the relationships among factors as in the nonlinear combination method. In addition, the process of determining suitabilities is more explicit than in the factor combination method and can deal with interdependence. A final method, *hierarchical combination*, could be viewed as a special case of rules of combination. However, because it is an important case, with general properties of its own, hierarchical combination is treated separately.

Rules of combination method

A simple, clearcut example of the rules of combination method is given by Kiefer (1965). After mapping the factors, he rates the types within the factors in a process equivalent to step 2 in Figure 3. He then states the general rule that the rating of the worst factor in a given region overrides the rating of all other factors. The rating of the worst factor is thus assigned as the rating of the combination of types for the given region, though often with exceptions. Kiefer, for instance, identifies sets of combinations that are to be rated by different rules, such as "a land unit rating 'optimum' in all factors except soil class and rating 'satisfactory' in soil class should be given an overall rating of 'optimum'" (p. 113). Instead of a linear combination to map step 2 into steps 3 and 4 as in Figure 3, the verbally expressed rules determine the composite ratings for the map in step 4.

The early warning system (Patri, Streatfield, and Ingmire 1970, Ingmire and Patri 1971) uses the rules of combination approach in deriving the "critical factor" map for rock and soil dynamics, which is essentially a suitability map for the likelihood of geologic activity. Rules of the following sort were used to define suitability levels.

> This broad category includes all cells which are scored in excess of 10% slope and are of a high erosion hazard category. They are outside of critical formations and expansive soil zones. They may include all but "active" and "major" faults (Patri, Streatfield, and Ingmire 1970, p. 132).

Although McHarg's work is usually associated with the ordinal combination method described in Figure 2, many of his studies are more accurately described in terms of rules of combination. A frequently used graphic procedure begins by following the factor combination method illustrated in Figure 5. Each of the factor maps is drawn with nominal data types. A code sheet is made by placing a piece of tracing paper on each of the factor maps in succession, outlining areas bounding each type and identifying them with a sequential code of letters or numbers as illustrated for the two-factor case in step 2 of Figure 5. This paint-by-number sheet is then printed as a base map for drawing suitability maps for various land use activities. However, instead of developing suitabilities through implicit judgment of each of the combinations at this stage, as in the factor combination method, a set of explicit rules of combination is developed. The map of step 4 is then colored to show suitability for a particular use by applying the rules to each combination on the coded base map. The only difference from Figure 5 is that rules are used to generate the ratings in step 3. The Medford study (Juneja 1974) provides a well-documented example of this approach, although the rules of combination follow a very simplistic and rigid form. The general rule used is not specific to the set of combinations, nor does it have any very convincing basis in terms of the natural relationships among factors. A single rule of this type is unlikely to be valid for the many different factors and land uses, because it is unlikely that the natural relationships involved will be so nearly the same.

A set of simple rules for the example of interdependence among slope, soil permeability, and subsurface material demonstrates the handling of interdependence among factors and the relationships of rules to the natural system being described. Assume that there are two slope types, greater than 25 percent and less than 25 percent; two soil types, well-drained and poorly drained; and two subsurface materials, clay and not clay. Then high suitability would include regions with slopes less than 25 percent or regions with slopes greater than 25 percent and poorly drained soil or regions with greater than 25 percent and not clay subsurface. Low suitability would include regions with slopes greater than 25 percent, well drained soil, and clay subsurface. These rules cover all of the eight possible combinations of the three factors. In contrast to the Medford study rules, these rules have a logic based in the understanding of the natural system being described rather than a single set of relationships repeated for all combinations regardless of the specific types and factors being combined.

Rules of combination can be applied to construct the composite suitability ratings map without having to deal with each possible combination individually. If the rules are stated explicitly, they can be used to generate maps directly without compiling a suitability table for all possible combinations. This is an obvious saving of effort compared to the factor combination approach. In addition, such rules are explicit and thus subject to scrutiny. The rules, if carefully devised, can also handle interdependence among factors.

Hierarchical combination

A more structured approach to rules of combination is based on the work of Alexander (1964). The basic concept is that a composite rating can be generated hierarchically. First, the combinations of types from each subset of strongly interdependent factors are rated for suitability as combinations, which thus permits consideration of interdependence among the factors within each subset. Then higher order combinations of the combinations from these subsets of factors are rated, with each lower order combination now treated as an integrated whole. This sequence of hierarchical combinations is repeated until a rating is achieved that includes all relevant factors. In this approach a combination of types in a subset is evaluated only once, rather than being evaluated each time it appears as part of a combination of types for all factors. The increase in efficiency over evaluating all possible combinations depends on the number of relatively independent subsets of factors that can be identified. Alexander and Manheim (1962) applied this concept in a somewhat different fashion for the location of a highway corridor.

A hierarchical method also was used for the impact models in the Honey Hill study (Murray, et al. 1971). However, the purpose for doing so and the criteria for carrying out the process do not seem to match the mathematical properties of the procedure. The evaluator was restricted to a set of three factors of his choice and was told to rate the combinations resulting from the two *least important* factors first; then these combinations (pairs) were combined with the *most important* factor. To handle interdependence it would be more appropriate to combine the two factors with the greatest *interdependence* first. The third factor would then, by implication, be interdependent only with the combinations of the first two factors. Regardless of the stated intentions in the Honey Hill study, this hierarchical combination is in effect what the logical properties of the procedure actually accomplish.

The neat three-by-three structure of the Honey Hill procedure has the appearance of a superficial gimmick with little realization of its logical basis. There is no inherent reason why one should be limited in all cases to three levels of three factors, nor to considering variation among only three sets of land uses. It is highly unlikely that knowledge of various impacts would happen to fit this rigid three-by-three framework. These comments, which also apply to some of the simplistic rules of combination described in the previous section, are not intended to denigrate the importance of the format in which data are presented for manipulation; the format should not, however, override the logic of the manipulations.

Table 1. Summary comparison of methods

Method	Handles interdependence of factors	Explicit identification of regions	Explicit determination of ratings	Additional comments	Example
Gestalt	Yes	No	No		Hills (1961)
Mathematical combination					
Ordinal combination	No	Yes	Yes	Involves invalid mathematical operations	McHarg (1969) pp. 31–41
Linear combination	No	Yes	Yes		Ward and Grant (1971)
Nonlinear combination	Yes	Yes	Yes	Required functional relationships generally not known	Voelker (1976) pp. 49 ff.
Identification of regions					
Factor combination	Yes	Yes	No	Requires a very large number of evaluative judgments	Wallace-McHarg (1964)
Cluster analysis	Yes	Yes	No		Rice Center (1974)
Logical combination					
Rules of combination	Yes	Yes	Yes		Kiefer (1965)
Hierarchical combination	Yes	Yes	Yes		Murray, et al. (1971) pp. 131–74

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Comparison, integration of methods

A comparison of some important characteristics of the eight general methods—gestalt, ordinal combination, linear combination, nonlinear combination, factor combination, cluster analysis, rules of combination, and hierarchical combination—is presented in Table 1. Because of the complementary characteristics of several of the methods, it is useful to apply more than one method in carrying out a land suitability analysis. This summary and comparison outlines circumstances in which the various methods are appropriate either alone or in conjunction with other methods.

Recommended methods

For simple, small, land resource inventories, the gestalt method is quite acceptable if qualified field personnel are available. A typical application would be a site visit, enhanced by making notes on aerial photographs, to determine land suitabilities for a small planned unit development. The disadvantage of the gestalt method is the implicit identification of regions and determination of ratings. It would be difficult to convince others of the validity of the suitability results if, for example, a change in zoning were required.

The three mathematical combination methods are either invalid or insufficient by themselves. The ordinal combination method is invalid and should not be used because of its assumptions and its inability to handle interdependence. The linear combination method should not be used as a general method for developing suitability maps because of its inability to handle interdependence. For particular sets of factors that can be shown to be independent, however, it is perfectly appropriate and relatively easy to use. The nonlinear combination method is generally insufficient by itself because the required mathematical relationships for the full range of costs and impacts are not known.

The factor combination and cluster analysis methods do not include explicit means for determining suitability ratings. The factor combination method is sometimes useful when an analyst is not sufficiently familiar with an area to make gestalt judgments to identify land types. If the study is otherwise relatively simple, it may then be reasonable to make implicit judgments as to the relative suitabilities of the regions. Although cluster analysis has been used in a few research studies for reducing the number of suitability evaluations required, it has not yet been shown to be worthwhile compared to the costs and benefits of using other methods.

For most studies, the best approach is to use the linear and nonlinear combination methods as a first stage, followed by rules of combination. First, incorporate the relationships among factors for which mathematical functions, either linear or nonlinear, are known by using the particular functions that apply. For example, soil loss and runoff can be computed from nonlinear relationships of soil type, vegetation cover, and slope. Also, certain construction costs associated with soil characteristics, vegetation, and slope can be summed as a linear combination to yield a construction cost figure. This preliminary stage yields additional factors—in this example soil loss, runoff, and construction costs. These new factors can then be combined with each other and the original factors (exclusive of their contribution to soil loss, runoff, and construction costs) using rules of combination. This second stage considers costs and impacts for which precise mathematical relationships are not known and yields an overall suitability rating for a land use. Extensive research projects at Harvard (Landscape Architecture Research Office 1974), the University of Massachusetts (Fabos and Caswell 1977) and Oak Ridge National Laboratories (Voelker 1976) include examples of the general approach of using linear, nonlinear, and rules of combination for appropriate components of a suitability analysis.

The approach just described involves a hierarchical sequence of combinations. First, a set of relationships is used to yield a new factor, runoff. Other relationships are used to yield other new factors such as soil loss. Then these new factors (or a subset of them) are combined. In this combination of new factors the relationships that yielded the runoff are *not* considered. The relationships between runoff and the other new factors are considered at the more general level. Hierarchy is a pervasive structure in thinking and accumulating knowledge (Simon 1969). It is therefore inherent in any complex procedure for generating suitability maps.

Interpretation of land suitability maps

No matter how obtained, land suitability maps provide information only about the supply of land at various levels of suitability for different uses. It is not possible to make evaluative, predictive, or normative statements about allocations of several uses to sites without also making some assumptions about the relative demands for the alternative uses. The necessity of dealing with both supply and demand in order to consider questions of land resource allocation is basic to land resource economics (Barlowe 1972). Gold (1974) has presented the argument for simple, artificial examples in the context of land suitability analysis. Some land suitability studies pretend, or at least appear to pretend, to yield immediate implications for allocation of land uses without recourse to explicit assumptions about relative demand for various land uses. It is on this point that the land suitability inventory work of the past two decades must be integrated with other land use modeling and analysis, which has been developed primarily in the context of

economic analysis. Many experiments already have been conducted in pursuit of analytical models capable of considering not only transportation and demand assumptions but also the site variations and environmental effects. (See, for example, Schlager 1965; Southeastern Wisconsin Regional Planning Commission 1968, 1969, 1973; Hopkins 1973; Landscape Architecture Research Office 1974; Hopkins 1975).

This taxonomy of methods points up the inappropriateness of the frequently cited ordinal combination method, the limitations of the linear and nonlinear combination methods, and the advantages of the general class of methods called rules of combination. It is hoped that the attempt to draw meaningful distinctions among frequently used methods will provide a basis on which further development of land suitability analysis techniques can take place.

Appendix.
Measurement scales for land suitability analysis

It is possible to manipulate numbers using any rules one might concoct as long as mathematical properties are not inferred from the numbers for which the conditions are not met. The book of readings edited by Maranell (1974) provides a wide ranging discussion of the general issue of measurement and scaling. This appendix is intended to clarify which conditions must be met to assure the validity of some simple numerical relationships usually assumed in making relative judgments for evaluation of suitabilities.

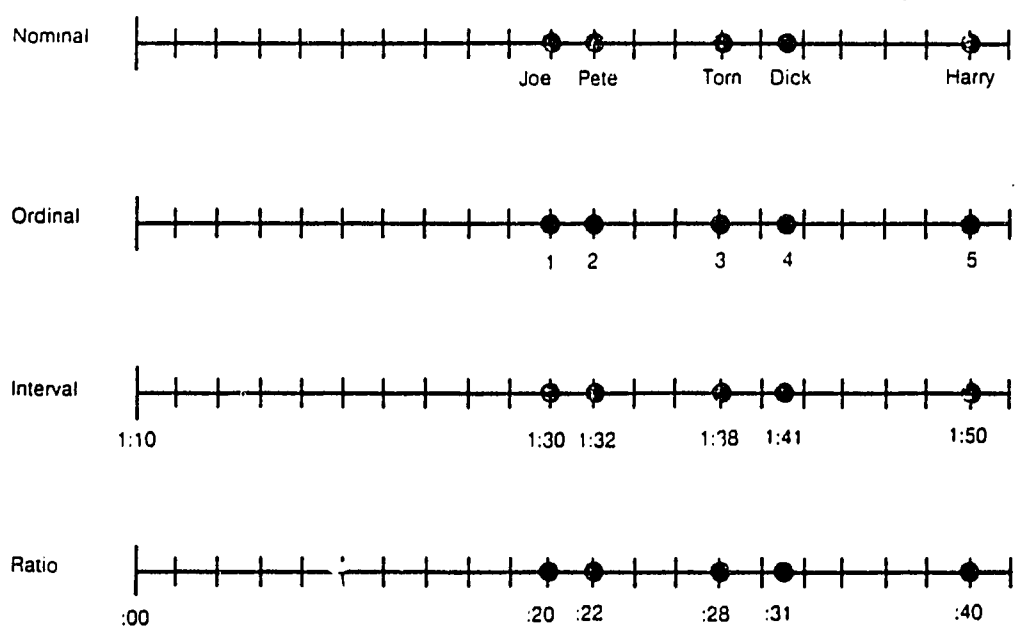
Perhaps the characteristics of the various measurement systems can be best understood by the example of a footrace illustrated in Figure A1. A *nominal* scale merely gives names to the elements, permitting only counting (five people ran the race) and perhaps some kinds of grouping (two males, three females). Soil types and land use types are examples of nominal identification in land suitability analysis.

An *ordinal* scale indicates the order in which people finished the race, permitting certain statements of preference, but none of the standard mathematical operations. Through the use of modern nonmetric, multidimensional scaling techniques, more information can be gained from ordinal data than was once thought possible. (See, for example, Green and Carmone 1970.) Hill and Tzamir (1972) have experimented with nonmetric scaling on a land use study in the context of evaluation. Rice Center for Community Design and Research (1974) has suggested some very preliminary ideas as to its use in land resource studies.

An *interval* scale—as meaured by a clock—indicates when each person finished the race in units of time, say one o'clock. This permits determining differences in meaningful units. Joe came in two minutes before Pete, which can be found by subtracting Joe's time from Pete's. These *differences* can be compared by multiplication or division. Joe was ⅓ as much before Pete as Pete was before Tom. Multiplication or division of the times themselves is, however, spurious. One does not know when the race started or how long anyone took to run it. On an interval scale one can say only how many units better or worse, *not* how many times or what percent better or worse. One can say that the interval between one pair of runners is twice that between another pair of runners, but not that one runner took twice as long. One special kind of multiplication is meaningful with respect to an interval scale. Multiplying all values of one interval scale by a constant has the effect of changing the unit in which measurement on that scale is expressed. One can multiply a time given in seconds by 1/60 and obtain time in minutes, which can then be compared to other times given in minutes.

A *ratio* scale—as measured by the stop watch—establishes a meaningful zero point, in this case the beginning of the race. It thus permits multiplication and division with numbers expressed on the ratio scale. Joe ran in half the time of Harry, which is found by dividing Joe's time by Harry's. Note from Figure A1 that adding or subtracting with the ordinal scale or multiplying and dividing with the interval scale would give meaningless results.

Figure A1. Comparison of representation of same data in different measurement systems



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A statement of evaluation using numbers, say zero through nine, could occur in any of these measurement systems. The digits could be simply names or could represent a ratio number system with a meaningful zero, a scale divided into nine units, and positions expressed to the nearest unit. Note that the result of applying this latter measurement system to the results of a nine-person race would not be equivalent to a ranking of the participants. One cannot determine the type of measurement system used by simply observing the information, but only from the assumptions stated explicitly, or more often, implied by the mathematical operations performed. The argument is not against zero to nine, but against failure to realize and accept assumptions of the measurement system being used. If an inappropriate zero point is chosen, the measurement results can be quite meaningless, as in the case of stating that Harry took 1.22 times as long as Joe on the basis of the interval scale where the zero point is 12 noon, but the race began at 1:10 p.m.

An interval number system is sufficient to identify the suitability of land for a given use as long as an analyst infers no ratio relationships between values. It may still be preferable to use a ratio scale with a meaningfully defined zero, because it seems to lead to better comprehension of the evaluation process and its implications. Rather than relying only on additive differences in thinking about relative values, one can also think in terms of ratios of the values.

At the risk of belaboring an important point, the crux of the issue is often missed in the usual example where degrees Centrigrade is called an interval scale, having an arbitrary zero, and degrees Kelvin a ratio scale with an "absolute" zero. The kind of scale and the concomitant mathematical properties can only be determined by whether one wishes to think in terms of ratios of distance from the freezing point of water or from the cessation of molecular motion. Using a ratio scale does not imply that there is some absolute zero, but simply that the zero point being used is a meaningful reference point from which to think about ratio relationships.

The zero point of suitability can be positioned in at least three ways. One approach is to rate benefits as positive and costs and impacts as negative so that the zero point is where no costs and no benefits occur. A second approach is to assume that the zero point represents the occurrence of all costs and no benefits. The third approach considers the lack of a benefit to be a cost and thus multiplied by -1. Therefore, in this third approach, the zero point represents no costs occurring and all benefits occurring.

The *added cost* concept implies a fourth temporary positioning of the zero for obtaining evaluation ratings. In this case the ideal site in the region for a given use is assigned zero cost for that use and increments of cost are related to the ideal, as additional costs for lack of benefits or occurrence of costs or impacts. Care must be taken to add the base costs of the ideal, and therefore to deal in total costs and an appropriate ratio scale, before applying any cost-benefit ratio criteria to projects or alternatives.

Author's note

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DOCUMENT

Some Constraints on Planning for Development in Post-Colonial Africa : A Concise Longitudinal Evaluation of the Sierra Leone Case

Thando D. Gwebu

Introduction

Three generic approaches appear to have characterized development-related investigations in Sierra Leone. The first category is typified by Harvey's strictly policy-oriented location-allocation investigations (1). The second is constituted by Cox-George's historical survey of the Sierra Leone economy (2). Finally, there is Saylor's research on the respective sectors of the economy (3). Because of their longitudinal orientation the last two approaches provide a broader perspective of national development. Consequently, both of them furnish the expedient background against which the latest National Development Plan (4) can be logically assessed.

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(1) See for example Harvey, M.E., "The Identification of Development Regions in Developing Countries", *Economic Geography*, 48, 1972, pp. 229-243. Harvey, M.E. et al, "The Application of a p-Median Algorithm to the Identification of Nodal Hierarchies and Growth Centers", *Economic Geography*, 50, 1974, pp. 187-202.

(2) Cox-George, N.A., Finance and Development in West Africa: The Sierra Leone Experience, London, Dobson, 1961.

(3) Saylor, R.G., The Economic System of Sierra Leone, Durham, N.C., Duke University Press, 1967.

(4) National Development Plan 1974/75 - 1978/79 (Freetown, Sierra Leone, The Government Printing Department, August 1974), pp. 11-17.

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This research will briefly consider the nature of pre-independence planning. Post-independence development policies will then be assessed up to the early seventies. Finally, the 1974/75.—1978/79 National Development Plan will be analysed in the light of its predecessors.

Pre-independence planning

That the nature of the pre-independence economy in Sierra Leone was externally-oriented is evident from these remarks by Cox-George (5):

> Hitherto the stress has been a mercantilist one, namely the development of the export economy. What is required is that greater emphasis should, in future, be placed on development of the internal market economy.

Not only was the country dependent on the outside for its capital goods but even for several simple foodstuffs. Cox-George thus recommended a rectification of this tendency by advocating economic independence (6):

> ... not only by growing more foodstuffs but also in the processing of the same. Then it might even aim at producing a super abundance of these for export as well. Rice, for example, can be exported to those places like India, Hong Kong and Japan from which in turn she can import cheap textiles.

Apart from calling for a general reassessment of the objectives of the pre-independence economy it was pointed out that the current planning lacked a systemic perspective. This observation was made in reference, apparently, to inadvertent oversight to sectoral interdependencies in the development process. Accordingly, Cox-George appealed for a comprehensive and dynamic approach to the planning process (7):

> The planning authority must realize that the economy is essentially a system of interrelated parts and that no part can develop in isolation from and without affecting others... the process can be seen as a symphonic whole and not as mosaic pieces fitted together as an afterthought.

The final important point he raised is related to an up-to-date data bank (8):

> ... in the future the budget (should) will be planned on something like perfect knowledge of the relevant data.

From the preceding discussion it is evident that both the aims and

(5) *Ibid.*, Cox-George, p. 305.
(6) *Ibid.*, Cox-George, p. 306.
(7) *Ibid.*, Cox-George, pp. 309-310.
(8) *Ibid.*, Cox-George, p. 310.

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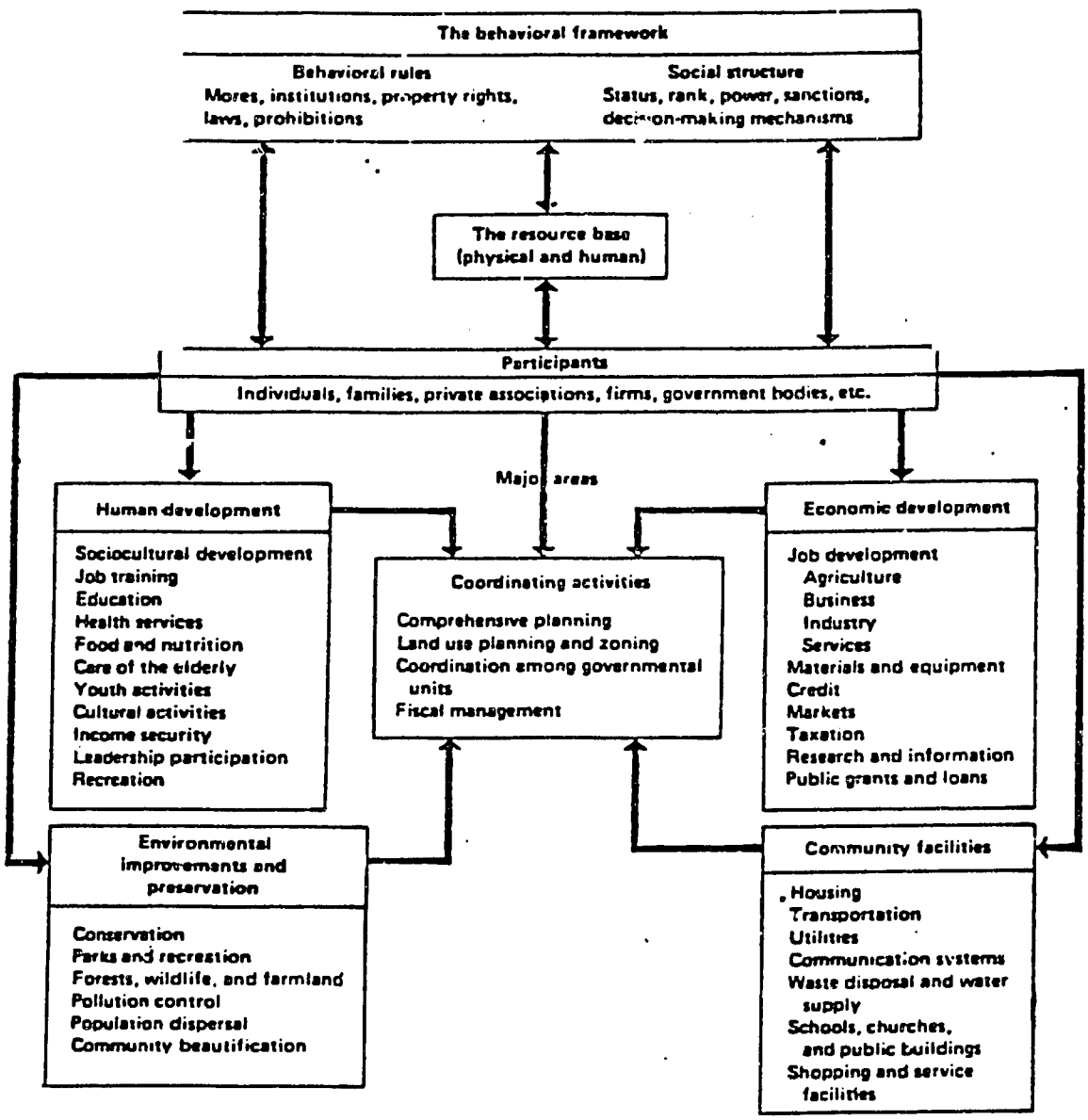
specific project activities and potential contributions from various disciplines is secondary. The emphasis is on developing the mechanisms involved in determining needs and goals and on developing problem-solving capacity since specific projects which may be initiated to accomplish the goals will often vary from community to community and from one rural area to another.

Thus, the position taken here is that a truly integrated approach to rural development, of necessity, involves (1) the land grant functions of teaching, research, and extension, (2) local, state, and federal agencies, and (3) the public--potential beneficiaries or victims of changes resulting from developmental efforts.

In summary, then, it can be stated that given (1) an adequate resource base, (2) a behavioral framework to guide actions, (3) participants from land grant and other educational institutions, agency personnel, and the public, and (4) sufficient coordination among these units, the goal of an improved quality of life is possible. This improved quality of life will be evidenced through positive changes in human development, economic development, environmental enhancements and preservation, and improvement in community facilities and services. These components or elements of the development process are more vividly presented in Figure 1--a model originally developed by Tweeten and Brinkman (1976) and revised by Carlson et al. (1981). Focus here is on the "participants" segment of the model with special attention being devoted to the most effective ways to organize or involve individuals, families, organizations, agencies, special interest groups, business firms, personnel from the land grant complex, and others in the delineation of problems and the coordination of ac-

FIGURE 1. Elements of Rural Development



SOURCE: Model originally presented by Tweeten and Brinkman, 1976:8 and revised by Carlson, et al., 1981:338.

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tivities necessary to bring about positive change in the four major areas in the lower portion of the model.

The Ideal Rural Development Plan

The ideal rural development plan is one which is based on results of careful planning and evaluation and one which involves all participants from start to finish beginning with "grass-roots" people and proceeding through the highest level in the bureaucracy. Persons at the individual and family levels should be consulted for the purpose of determining needs as they perceive them and to provide their assessment of what is needed to bring about positive change or an improvement in quality of life. Persons at the leadership level--including businessmen, local politicians, organization leaders, etc.--should also be consulted to gain their opinion and knowledge about problems facing the community and what they feel is needed to bring about positive change. Problems, needs and potential solutions provided by these two groups should be compared and reconciled where differences exist since it is very likely that problems and proposed solutions as perceived by members of these two groups will be somewhat different. Land grant and agency personnel can assist with this process at various levels beginning with problem identification and needs assessment.

Summaries of these "reconciled" problems, needs and proposed solutions from communities across the affected area or unit should then be evaluated by appropriate professionals from the land grant complex, agencies and other relevant entities to determine, from a logical, theoretical and practical perspective, whether these problems are real and

to determine the suitability of solutions proposed. It is at this level that alternatives, subject to the resource base, the behavior framework, and potential impact on the community, will be explored and evaluated. Each viable alternative should be presented along with expected positive as well as negative influences. These alternatives should then be prioritized by persons at the individual, family, leadership, academic and agency levels. Community leaders, with input and assistance from the residents and professionals in the area, will select the alternatives holding the greatest potential for positive change. The plans should include: (1) mechanisms for providing for or compensating those persons adversely affected, (2) mechanisms for aiding individuals in developing the capacity to sustain themselves over the long run as well as (3) provisions for those persons unable to participate in the development process because of physical or other handicaps. This, by necessity, implies that the rural development plan must be balanced and include provisions for programs aimed at (1) human development, (2) economic development, (3) environmental enhancement and preservation, and (4) improvement in community facilities and services. Specific projects or programs, as identified by the participants, within these broad categories (see Figure 1) can be delineated and addressed utilizing assistance from persons or professionals in the appropriate disciplines.

In addition to involving participants from the various groups in the development process, they should also be involved in developing the strategy for implementation. Programs should be available and assessable to all persons in need of the service or assistance without undue hardship. This can only be accomplished through cooperation and coordination among

the participants at the various levels in the development of the delivering system.

Finally, on-going evaluation is an essential part of successful rural development. Participants as well as sponsors at the local, state, regional and national levels, should establish mechanisms for assessing the degree to which steady progress is being made in effectively and appropriately addressing needs and problems which have been identified.

Discussion and Conclusion

In planning for rural development, there is a tendency for attention to focus on specific projects, usually concern with improvements in nutritional well-being, housing conditions, and employment opportunities, or with the survival of small farms. While these are important means to achieving the goal of improved quality of life, concern with specific project activities has been low-keyed in this presentation. Instead, attention has been directed toward recognition of the fact that whatever specific activities are undertaken in the rural development process, they must be self-sustaining and in keeping with the needs and desires of the persons affected if they are to be successful.

This brings us to the second point stressed in this presentation; that is, a truly integrated approach to rural development requires careful planning, cooperation, and coordination of efforts by all involved in the rural development process--the land grant complex, federal agencies, other public and private organizations, and citizens who are most affected by proposed programs and changes. Rural development programs are often initiated and planned by concerned "specialists" in the federal and land

grant bureaucracies with little or no input from the intended recipients of the benefits of such programs. We must not forget that the most effective developmental programs are those where the people affected understand the proposed program, its purpose, and can anticipate both its costs and benefits. Therefore, the importance of involving rural people in the study, planning and implementation processes of rural development cannot be overemphasized.

The time has long-since passed when unlimited federal funds are available for rural development programs. While limited funding continues, the government has also recongized the need for local people to take a more active role in solving local problems. One of the more recent indications is this conference and the mandate of the Office of Rural Development Policy (ORDP) to pursue "grass-roots" strategies to total development.

The mandate here for citizen input into rural development processes may in many ways be inconsistent both with our present ways of doing things and with our perceptions of how rural development should be pursued. But based on the numerous "almost" unsuccessful experiences with rural development programs, it may be time for us to re-evaluate our present process and begin putting forth concerted effort to make sure that rural development programs benefit those for whom it is intended.

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A "Negotiating Model" in Integrated Rural Development Projects

Eric J. Miller

[Neither a "top-down" nor a "bottom-up" approach to rural development is wholly satisfactory. This article proposes the alternative of a negotiatory relationship between government and rural villagers, and examines the ingredients of its successful application in a Mexican project.]

Efforts at rural development in Third World countries have generally not been crowned with success. Indeed, for some "beneficiaries" the results have been disastrous. For example, peasants who have been persuaded to abandon subsistence farming for a single cash crop such as cotton may prosper for a while, but two or three successive years of infestation or depressed world prices can force them off the land. In other cases the innovation just disappears and the peasants return to the *status quo ante*. Large numbers of rural drinking water systems, for example, which are proudly inaugurated as a contribution to villagers' health and welfare, are out of use within a couple of years, apparently because the local communities lack the skill or will to operate and maintain them.

Our response to these failures has been to move away from isolated crop improvement projects or health projects towards programs of integrated agricultural development and, in a few countries, integrated rural development. Such a program involves a wide range of interventions and investments in farming technology, rural industry, credit, commercialization, road-building, transport and other areas, designed to bring about economic advancement; and alongside these, projects concerned with nutrition, health, housing, education, and so forth, intended to improve the quality of rural life. On paper,

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at least, this "total system" strategy looks capable of bringing about the massive transformation that is required; and on paper, too, the achievements can seem impressive in terms of the numbers of wells dug, hectares irrigated, schools built, and so on. But all too often in the process of implementation the concept of integrated development gets lost. Objectives are confused; methods are inadequately worked out; government agencies find it easier to compete than to collaborate; officials are incompetent or corrupt. As a result, the experience of the recipients is often of isolated and even capricious actions, which seem unrelated to each other or to local needs. Programs such as these therefore risk becoming more elaborate and costly mechanisms for producing the same failures as before.

The Government of Mexico introduced its integrated rural development program known as PIDER in 1973. It was a large and ambitious undertaking, ultimately intended to reach some 20,000 rural communities with 300 to 3,000 inhabitants each. Between September 1973 and November 1976, I worked as a part-time consultant to the Directorate of Public Investments, which was the division within the Ministry of the Presidency responsible for establishing and administering the program. Initially, the Directorate was seeking advice on the major organizational problems posed by the program, which called for the coordinated intervention of many different federal ministries and agencies at state and local levels. Since organization is a means of carrying out a task, we had to consider what the task of the program was. Each agency had its own specialized activity--roadbuilding, rural electrification, irrigation, soil conservation, setting up village health centers, and so on--and all of these could be seen as potentially contributing to rural prosperity and welfare. But the critical word is "potentially." These new installations and projects were no doubt necessary conditions for development, but they were not sufficient conditions. They would contribute to development only if the rural communities themselves were able to use them and build on them. At that stage, therefore, I saw the task of the program as "to procure a self-sustaining process of rural development." The problem was to identify the kind of relationship at the interface between the "developers" and their "client systems," that would enable this to happen, and then to provide the conditions for the developers to take up appropriate roles. This was my main preoccupation over the next three years.

From my initial discussions in Mexico City and visits to the field, it rapidly became clear that, sometimes explicitly but often implicitly, two conflicting models of the development process were operating. These can be summed up as "top-down" (Model A) and "bottom-up" (Model B). Seldom did they appear in practice in a pure form, and indeed the same individual might seem to oscillate between them--perhaps voicing a Model B philosophy while acting on Model A assumptions. However, the confusion was not only his: he was expressing something of the multiple and con-

flicting objectives of the rural development program that are familiar in Mexico and elsewhere. At the risk of stating the obvious, the distinctions nevertheless seem worth spelling out.

Model A: Top-Down Development

Increased agricultural production is a significant objective in all national programs I know of. The document stating the objectives of the Mexican program was careful to point out that this was a means of enhancing rural prosperity rather than an end in itself; but not all the participating agencies would regard this as a meaningful distinction. Increased production is certainly a national objective--in order to feed the growing urban population, reduce imports, and earn foreign exchange from exports--and it is an explicit part of the mandate of the Ministries of Agriculture and of Agrarian Reform. That, then, is the message that these ministries' officials, experts, and extensionists carry with them when they go into the field. They tend therefore to behave as if the primary task of the program is to develop and organize rural communities so as to meet national production goals. From this it follows that the local community and the population of peasant farmers within it is conceived as a subsystem within a national production system.

There is a close analogy here with a commercial holding company seeking a return from its investments in subsidiary companies. And indeed it is noticeable that this formulation of the objectives is associated with the application of principles of scientific management to community development: typically, attempts are made to organize each community according to a standard type of democratic, participatory system that requires a collective structure, election of office-holders, division of labor, definition of functions, delegation of responsibilities and authority, and use of incentives. An underlying assumption of Model A is that there is a substantial consistency between governmental economic objectives and rural community needs. National programs to achieve these objectives will benefit communities by increasing their prosperity. The orientation is technocratic: the experts know what needs to be done. Accordingly, any resistance displayed by the communities is irrational: with education and persuasion they will come to see that their own self-interest coincides with the national interest.

Model B: Bottom-Up Development

It is always a stated objective of rural development programs to rectify gross inequalities of wealth; and one does not need to be a Marxist to recognize that much rural poverty (though by no means all) is a consequence of historical subjugation which has generated demoralization, apathy, fatalism, and submissiveness. People are trapped in a cycle of deprivation from which they feel incapable of escaping and have given up trying; they do not perceive themselves as having any

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choices. Following from this diagnosis, the primary task of Model B can be stated in some such terms as these: "to restore the self-confidence that will release energy and motivation for self-development," as stated by Paulo Freire (Cultural Action for Freedom, 1972). His starting-point is a process of adult education which enables the peasants to examine and question the situation they are in. They learn that their impotance is a consequence not of inherent inferiority but of historical processes. These are reversible. Government aid is not a privilege that they should feel grateful to receive, but something they have a right to demand, even to fight for. In effect, the postulate is that they need to engage in something equivalent to revolutionary activity in order to regain a sense of potency and thereby to release energy for constructive self-development. Model B can slide imperceptibly into revolutionary activity for its own sake: where the conflict of interests becomes total, the primary task is to destroy the oppressors.

Neither Model A nor Model B was operating in a pure form within the PIDER program. What I discovered from my discussions and field observations in 1973 and early 1974 was that there were more signs of the top-down than of the bottom-up model, but that in fact one could identify the emergence of a third model, which was a kind of compromise between them. Official program policy listed the following criteria for selecting investment projects:

1. Highest priority should be given to productive projects which guarantee large-scale permanent employment...
2. In the social field, the drinking water, health, education and housing projects should foster a positive change in way of life and, still more, a necessary change of attitudes.
3. Priority will be given to complementary projects which strengthen the profitability of investments already made.
4. In all cases an attempt will be made to satisfy the needs expressed by the people, and projects will be carried out only at the explicit request of the communities.

Elsewhere in this policy document, issued in April 1973, there was emphasis on promoting participation, "so that a mechanism can be established which permits planning from the bottom up." Community representatives were to be involved not simply in planning local developments but in the design of regional strategies.

The intentions sounded admirable; but unfortunately a development program is influenced less by good intentions than by the structure and culture of implementation. Usually there is strong pressure to act, and to act quickly, as if inequities that have been condoned for generations should now be put right overnight. The dilemma of the Mexican program, as of others, was that although the importance of inculcating an ethos

of community self-development was recognized, the very process of undertaking a large and rapid investment in productive projects and amenities tends to put the community in a dependent posture. a posture which is antithetical to self-development.

Model C: Enlightened Paternalism

The model actually in operation can best be described as "enlightened paternalism." The stratogic unit for development with the program was a "microregion." This would be identified on the basis of ecological and socio-economic uniformity and *prima facie* evidence of developmental potential. The average population was 75,000, and so it might contain 50-100 communities eligible for investments under the program. An interdisciplinary team of some 20 members, drawn from the various agencies involved, would make an intensive tour of the microregion. Each community would be visited, perhaps for half a day, in order to survey its resources and needs and to identify possible projects. Towards the end of the visit all the men in the community would be assembled, and the team would outline the projects it had in mind and ask for comments and alternative suggestions. Essentially that was the moment of participation. The team would subsequently assemble all the data from the field visits, devise an overall strategy for the microregion, make preliminary estimates of sums to be spent for various types of investment (e.g. road-building, soil conservation, fruit-growing), and then select the most deserving projects under each heading from the total range of possible projects that had been listed originally. These recommendations then had to be approved both by the headquarters of their respective agencies in Mexico City and by the central organization of the program itself. It would be at least six months later that the community would be told what projects, if any, had been earmarked for it.

Sometimes the microregional strategy had a discernible coherence; but often it seemed more like an aggregate of projects. At the level of the community, any concept of a development plan was rare indeed: investments and interventions seemed arbitrary and often unrelated to each other or to priorities that the local population itself might have set. It could be said that the "developers" were behaving as if the primary task of the program was to demonstrate the Government's good intentions. Their relationship to the communities was that of benefactor to beneficiary. They came equipped with a gift-list of projects that they could carry out, sometimes quite competently. Although they paid lip-service to the idea of bottom-up planning, this was for the future; in this initial phase the recipients were perceived as incapable of assessing the options open to them or of choosing among them.

Such arguments had some validity. It takes time and skill to help a community to formulate its needs. Many peasants were distrustful of the Government: promises had been made in the past but never translated

into action. Donation of, say, a drinking-water supply can give a community a feeling that it is being valued and help it to acquire some self-confidence. However, in some ways the integrated program was putting the beneficiaries into a more extreme position of passive dependence than some more conventional development projects that had been administered by individual agencies. Rural electrification schemes, for example, had required that part of the costs should be borne by the communities that benefited; and this encouraged each community to organize itself and to acquire some identity as a client system. Under the PIDER program such contributions were waived, and an incentive to organize was removed. The benevolent paternalism of Model C was therefore tending to hold the communities in the passive-dependent posture, and was doing little to encourage them to move into the more active, autonomous, entrepreneurial posture that was necessary if they were to become capable of self-sustaining development.

Model D: A Negotiating Model

My proposal was that the program needed to move towards a "negotiating model," which was in fact more consistent with its intentions. My thinking can be summarized as follows: Essentially the top-down Model A and the bottom-up Model B are both in a way right; the search for areas of consensus and compromise between them, implied in the enlightened paternalism of Model C, while it may have been necessary to gain sanction for the Program, was not the best solution for development. A Model D that overtly recognized divergences as well as commonalities of interest would be developmentally the most productive. The fact that a community comes up with an assessment of its own interests which does not match the assessment that a governmental agency has made does not mean that it has either to be blamed for its irrationality or praised for asserting its independence: it is simply a fact, and a predictable one at that. Correspondingly, the observation that the governmental agency is trying to implement policies that do not find local acceptance does not imply that one should either criticize it or sympathize with it. Although the Federal Government acts with the ultimate authority of the people in the service of the people, it will not please all of the people all the time. These facts, then, are not to be swept under the carpet: they are matters for examination and for negotiation. It is through such a process at the interface of community and agency that the peasant begins to find the meaning of his role as a citizen of the Republic, and begins genuinely to participate in planning for development; while the agency members for their part begin to question the relatedness of federal policies to local concerns. Both parties learn from the transaction. Assumptions get tested and modified. It is a process, in other words, that gives some reality to that over-used slogan, grass-roots democracy.

The primary task of Model D could be defined as "to provide resources to help each community to formulate, negotiate and implement

its own community development program." The first element of the model, then, is a community development program formulated by the community itself. This requires making available a consultancy resource through which the community can become aware of the possibilities for change. However, in designing a strategy for itself the community will need to take into account the development programs of neighboring communities and of the administrative district of which it forms a part, and the policies and resources of relevant Government agencies. So we have as a second element the concept of joint planning and programming. These lead to, third, the negotiation of a contractual relationship between the government and the community, in which each party undertakes to contribute resources to the community development program that has been negotiated.

Much of my work as consultant to the program from 1973 onwards was directed towards shifting from Model C to Model D. A fundamental change was required in the relationship between agency representatives in the field and the client communities. As I have indicated, these representatives were seen, and to some extent saw themselves, as benefactors; the community was the recipient of bounty. The agency representatives had the resources; the community had none. The representatives had the power to give or withhold projects according to their picture of whether the recipients could make effective use of the investment in them; the community had no control over this process. The transaction was one in which the situation was totally defined by the agency representatives while the community remained in a passive and dependent role. My observations revealed, however, that the authority and power of these officials in the field were mythical. The real power lay with their agency superiors in Mexico City. Indeed, the relationship between these superiors and their field representatives corresponded almost exactly to my description of the representative-community relationship. My proposition was that the administrative system, and the nature of these representatives' authority or lack of authority within it, had a determining influence on the nature of the development process through which the representatives related to the client communities. Unless the field representative could exercise authority in negotiation (instead of having to refer all decisions to his superiors), the community was unlikely to discover its own capacity to do so. The same applied to relations between agencies: to expect that the peasants would organize themselves for collaboration was hardly realistic so long as the participating agencies themselves had not learned to work together toward a shared objective.

Besides helping to introduce specific organizational and administrative changes that would push or pull authority outwards from the center to the field, my role had an educational component. I was trying to teach my clients about systems. The task of the development process, as I saw it and still see it, is to produce robust self-managing systems.

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Any potential intervention has to be evaluated for its systemic consequences; and, as the negotiating model suggests, the nature of the relationship between development agency and client may be more significant for development in this sense than the content of specific projects. In this I was challenging the conventional wisdom not only of Mexican government agencies but international funding bodies, such as the World Bank and the Inter-American Development Bank, which, even in an integrated rural development program, call for an economic cost-benefit justification of each project and insist on the lowest-cost alternative. With such requirements one should not be surprised at the number of rural health centers which look impressive in the statistics but remain unused.

Ingredients of Successful Projects

With or without the benefit of my advice, the program was expanding rapidly. By the end of 1975 about 5,000 communities all over the country had received or were in the process of receiving investments under the program, and with some there had been contact for two and a half years. We had here a large-scale natural experiment in which it was possible to generate and begin to test hypotheses. As a start, I paid three short visits over the next few months to regions where the program was said to be showing signs of "success." The criterion I adopted was that there should be evidence of people beginning to manage their own development and, in particular, of reinvestment. For example, in one village, where a workshop provided employment and several cooperative poultry-keeping projects had been introduced, some of the income had been reinvested; but, more importantly, it was being used to finance new productive activities through purchase of cattle and of sewing-machines to make clothes for sale as well as for family use. In addition, a percentage of profits from poultry-keeping was paid into community funds, which were being applied to a children's playground and new public buildings. In another case, in order to provide permanent employment for landless laborers who had worked on road-building at the beginning of the program, a small sawmill was built with a contract to supply posts for rural electrification. This generated a substantial surplus which, with the agreement of the workers, was used to seed further rural industries. A collective organization was formed, and in little more than two years it had set up nearly 200 small enterprises providing about 1,500 new jobs. Control of the individual enterprises and of the corporation as a whole was vested in the workers, who were mainly women and girls.

From these and other cases it was possible to identify some common factors. Characteristically, a PIDER representative had exercised leadership in getting a client group to visualize a desirable and attainable future state, and to commit itself to taking the first steps toward achieving it. He had sufficient authority (sometimes reinforced

by political power) to commit contributions from the program, but these usually took the form of materials and technical assistance. The clients were expected to contribute labor to and often manage construction and other activities. He and/or members of his team were in frequent contact with the client group; this seemed to have an important function in sustaining the vision of the future before there were any concrete achievements. Thus there was a good deal of dependency, even charisma, in the early phases, but this was not a source of self-depreciation by the clients. The leadership role had been so managed that the hope and potency invested in it had been routed back to the clients in the form of a growing belief in themselves and their own capacity to bring about changes. They themselves were taking initiatives--taking over the vision, as it were--to which the representative was able to respond flexibly on behalf of the program. Explicitly or implicitly, the criterion he used was whether the proposal would enhance the clients' capacity for self-management; and so he might use program resources to back projects that would not always stand up individually to a stringent cost-benefit analysis. (He seemed to have the freedom to do this partly because of the savings obtained through high participation of clients in earlier projects.) Management and initiation of projects had required a repatterning of existing organizational arrangements in the client system or the emergence of new structures (such as the collective corporation). Finally, the changes in internal structuring seemed to be directly related to and contingent on changes in the relatedness of the client system to its external environment.

I found that these brief field studies had sharpened my insight into underdevelopment and therefore the processes of development. Underdevelopment could be defined operationally as a relative lack of control over relations with one's environment, where that includes both the local physical environment and the external environment that comprises the wider socio-economico-political system. Specific aspects of these relations--economic and other--can be identified, analyzed and sometimes measured. Development, then, implies a change in such relationships in the direction of influencing and controlling the environment, instead of being controlled by it--a change from impotence towards potency. Following from this, I could assert much more unequivocally that *the primary task of a development program is to help the client system to increase control of its environment.* That furnishes the criteria for effectiveness; that is the task for which the development agency needs to organize itself.

Four aspects of this task may be identified. Two of these are familiar enough; but I suggest that the significance of the third, and, in particular, the fourth is insufficiently recognized.

The first aspect is development of the human resources of the community. It is obvious that education can inculcate new techniques and

skills; literacy gives access to alternative values and goals. Similarly, improved nutrition and health can release greater energy for existing and new activities.

The second aspect is enhancement of the physical resources of the community. This is the objective of many development agencies, which, as we have seen, often measure their performance by the number of wells dug, health centers constructed, households provided with electricity, etc.

However, as with the example of drinking-water systems, installation is not synonymous with utilization. These projects, therefore, are to be regarded only as means, not as ends in themsleves. The criterion of effectiveness lies in my third aspect: have they helped the community to extend its control over its physical environment? An extentionist may work hard and successfully to arouse enthusiasm for a new agricultural technique, which really seems to be moving the boundary between the farmers and their physical environment; but after two seasons of successful operation with markedly higher yields, the farmers regress to previous methods. Sometimes this is simply because the extensionist has failed to ensure that supplies of the requisite seeds and fertilizers will be readily available. Sometimes it is because he has misjudged the goodness of fit between the innovation and the prevailing culture. Extensionists may also ignore the pragmatic wisdom of peasant communities that has enabled them to survive. (P. R. Jennings, Scientific American, Vol. 253, No. 3, 1976.) They are not interested in crops that produce a very high yield but only in good years; the varieties they have learned to trust are those that will minimize the chances of a total crop failure in the bad years. But often the most plausible explanation in such cases is simply that the farmers have not acquired the skill to manage the new process themselves; they have been dependent on the extensionist, so that only his continuing presence has permitted the innovation to be sustained.

So I come to the fourth aspect: that the community will not achieve greater control of its local physical environment, or the achievement will not be sustained, unless the change is also accompanied and reinforced by corresponding and more permanent changes in relations with the external environment. The community also needs to become more autonomous and influential in managing these relationships. Many of these changed relationships will be economic: for example, the community sells produce instead of exporting manual labor; it sells its produce in processed form instead of selling it unprocessed (for example, cheese instead of milk); it diversifies its products; it extends its control over distribution and so commands higher prices; and so on. Obvious though these points may seem, it is surprising how often they are missed, even in supposedly integrated development programs. Extensionists promote higher yields without considering the process of commercialization, so farmers have little incentive to increase output if all

the extra profits go into the pocket of the traditional middleman. Nor is a government purchasing agency always a viable alternative. R. Ackoff, writing on development planning in the Mexican context, cites cases of agency employees being bribed by the middlemen to reject farmers' offerings, which were then sold to the old buyers at depressed prices. (Operations Research, Vol. 25, 1977, p. 207.) Farmers may therefore need to be helped to establish their own cooperative marketing arrangements, bypassing the middleman, if they are to get a proper return.

Along with such economic gains, a less obvious, more subtle and more significant change seems to occur: a change in the community's identity and self-image. As a result, for example, of bypassing the old channels and managing distribution themselves, the people acquire a different--more potent--image in the external environment, and this in turn reinforces an emerging image of themselves as more potent, both collectively and individually. In one of the villages mentioned above, several different family enterprises were engaged in poultry-keeping. Among themselves they organized their production cycles so as to maintain a steady overall output, and in the market of a nearby town they manned a stall to sell the dressed chickens. The stall bore the name of the village and quickly acquired a reputation for quality and reliability. This in turn helped to sustain the collaborative arrangements, and was quite evidently a source of pride and added self-confidence in the village as a whole. In this way, technical and structural changes become confirmed by a cultural transformation. The outcome, then, is a system that has discovered the possibilities of exercising autonomy and choice and has become capable of managing itself in a self-sustaining process of development.

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Top-Down and Bottom-Up Rural Planning in South Korea

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[This article outlines, first, the highly successful "top-down" rural development program of the Korean government; and second, a group of projects intended to establish "bottom-up" decision processes, supported by a foreign private agency, also with successful results. In conclusion, some lessons from experience are analyzed.]

South Korea has a land area of about 98,500 square kilometers and a population of about 37,000,000, making it one of the most densely populated countries in the world (374 persons per square kilometer). Less than 25 percent of the land area is arable, so the actual concentration of people, even in rural areas, is much greater. Because winters are fairly cold and dry, double cropping is only possible in the southernmost provinces. However, winter vegetable growing in vinyl greenhouses has been widely adopted in recent years.

In the 1960s and 1970s South Korea has undergone an extraordinarily rapid rate of industrialization, urbanization and economic growth. Starting from a predominantly agrarian society, its urban population rose from 28 percent of the total population in 1960 to nearly 55 percent at present, with a corresponding decline in the rural population. The Gross Domestic Product (measured in constant prices) grew at an average annual rate of 8.5 percent between 1960 and 1970, and 10.3 percent from 1970 to 1976. Per capita real income rose at an average annual rate of 7.3 percent from 1960 to 1976, reaching an average of US$670 per person in 1976.

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Despite an absolute decline in the agrarian population (due to rapid urban migration and an increasingly effective birth control program), agricultural output grew at an average annual rate of 4.5 percent from 1960 to 1970, and 4.8 percent from 1970 to 1976. At present there is an actual shortage of agricultural labor in South Korea—an unusual phenomenon in Asia.

In contrast to most other Asian developing countries, the distribution of wealth in South Korea is fairly equitable, comparable to that in the United States. This is in large part a result of measures that raised the position of farmers, who are in developing countries the poorest members of society. A thoroughgoing land reform program was carried out in 1949/50. As a result, while over 83 percent of farm families depended to a greater or lesser extent on landlords in 1947, in 1964 (after the reform) the figure had dropped to about 30 percent. During this same period the percentage of completely landless households in the farm population fell from more than 45 percent to about 7 percent.

As noted above, the pace of agricultural production picked up in the early 1970s. Grain production since 1973 has increased at a rate of about 7 percent annually, mainly due to the successful adaptation of new varieties of rice and barley to Korean soils and climate. Urban and export demand for agricultural products, particularly cash crops such as fresh vegetables, fruit, and meat, stimulated even greater increases in productivity in some of these crops. While demand is, of course, an essential stimulus, the rise in farm production has only been possible because more fertilizer and pesticides, improved irrigation systems, greatly increased amounts of rural credit, and improved technical knowledge have been made available in recent years.

Increased productivity and rising prices for agricultural products have improved farm income and the farmers' terms of trade. Better transportation, rural electrification and a rapid expansion in educational facilities have also contributed to the rising quality of rural life. In sum, there has been since 1971 a real transformation in rural living standards with average farm household income reaching almost that of urban workers. Development is the main preoccupation of most Koreans today. In rural areas new crops, new agricultural methods, and dramatic improvements in social infrastructure are characteristic of most villages.

The *Saemaul Undong* Program

While the economist tends to see the causes of this rural economic growth and social transformation in such factors as market incentives, improved seed varieties, and the greater availability of agricultural raw materials and services to the farmer, the Korean Government attributes most of the recent progress to the successful implementation,

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starting in 1971, of its *Saemaul Undong* (New Community Movement). Although the main focus of the New Community Movement has been rural development, it also has another dimension—the fostering of a new ideology.

In recent years social commentators as well as political scientists have deplored the lack of a genuine national ideology in South Korea, maintaining that anti-Communism and the pursuit of material progress were not enough to provide inspiration as national goals and symbols. By 1972 it was apparent that the New Community Movement in its broadest context constituted part of a determined attempt by the Government to fill this ideological gap. The attempt is still being pursued, and strenuous efforts are made to infuse every aspect of life —from garbage collection to poetry writing—with the Saemaul spirit. The Movement adopted "self-help, cooperation, and diligence" as its motto, and President Park's frequently repeated words, "Let's live better," became a kind of slogan. Building on both the hierarchical and collective traditions, the Movement stressed obedience to expert, paternalistic administrative leadership and an extension of the idea of community to encompass the entire nation. The ideological component was, of course, closely related to the Park Government's objective of expanding and consolidating grassroots political support.

By the winter of 1971-1972 a major effort had been launched to get the majority of farmers in all 35,000 South Korean villages involved in cooperative village improvement projects. Supplies of cement and steel reinforcing rods were made available by the authorities, and villages were encouraged to use them to improve roads, bridges, wells and sanitation facilities. A major program was also launched simultaneously to persuade farmers to replace their thatched roofs with tile, metal or composition. The expectation was that through participation in projects having an immediate impact on the village environment, farmers would realize the benefits of working together during the off season, and a spirit of progressive community activism would be fostered.

Because of unrelenting pressure from the top, bureaucratic efforts to achieve the movement's goals were intense. Saemaul became the main focus of activity for all local administrative agencies, and thousands of other officials from the capital descended on the provinces to inspect, exhort, direct operations, and, to some extent, compete with local officials. The result initially was often confusion and bureaucratic overkill, while the astonished villagers struggled to comply with mounting and sometimes conflicting demands for compliance with various aspects of the overall plan.

In the beginning most farmers distrusted the motives of officials and resented their constant interference in village affairs. After all, nothing good had ever happened to rural society before as a result of

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closer contacts with the bureaucracy. Where villagers were slow or reluctant to organize for carrying out suggested projects, official pressures were applied that often amounted to direct coercion. For example, if several farmers in a village were reluctant to replace the traditional brush fences around their houses with cement walls, jeep-loads of men from the county seat might arrive and simply tear them down. Similarly, there were occasions when house owners who were unwilling to make the substantial investment necessary to replace their thatched roofs with composition or tile might return home from a market trip to find the thatch gone and their homes open to the sky. Such excesses, which reflected the concern of local officials with producing quick results to please superiors, generated a lot of resentment and cynicism during the first two or three years of the movement.

But since 1973 attitudes in most places have gradually shifted, as farmers discovered that all the excitement and effort did, in fact, result in substantial benefits. Each village is given a rating by the county chief in accordance with its accomplishments, and local pride has in many cases been stimulated to a high competitive pitch among neighboring communities. Where village leadership is in the hands of determined activists who are also skillful in maintaining good relations with other members of the community, a considerable degree of constructive enthusiasm has usually been generated and sustained. Once the most influential men in a village are committed to pursuing the Movement's goals, others will nearly always follow, and non-conformists are subjected to subtle but extremely effective social censure. As a result, although distrust and reluctance prevailed a few years ago, most village councils are now eagerly drawing up ambitious development plans and begging for official support to help carry them out.

There is a good deal of variation from one village to another, and while some degree of participation exists everywhere, such factors as the quality of leadership, geographic accessibility, the degree of village cohesion (or conversely, of internal division, usually along kinship boundaries), the distribution of wealth, and commercial opportunities for individual profit, all vary from place to place, and all affect the extent and intensity of involvement in collective community efforts. Nevertheless, in spite of uneven performance, it is undeniable that the Saemaul movement has transformed the appearance of Korean villages, fostered the successful completion of a large variety of cooperative, self-help projects, and promoted more effective working relationships, both among farmers and between farmers and local officials. It has also given villagers a sense of participation in a momentous national effort, with strongly patriotic overtones. Any visitor to rural Korea today can observe the pride in recent achievements and a confidence in the future that were almost entirely absent ten years ago.

The government's claim that it is the New Community Movement that is responsible for bringing about the new rural prosperity is not en-

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tirely convincing. Actually, it has become increasingly difficult to analyze cause and effect in rural development, because the dimensions of the movement as a "nation-building" ideology have been expanded to include everything positive that happens in rural society. It seems clear, however, that it is not so much that Saemaul has sparked rural prosperity, as that it has been pushed in a context of relative rural prosperity that is the result mainly of other factors: 1) the widespread successful adoption of new, high-yielding varieties of rice and to a lesser extent barley; 2) the maintenance of favorable subsidized grain prices by the government; 3) the increased availability of more effective agricultural extension services; 4) the greatly expanded urban market for a wide variety of new cash crops; and 5) improvements in transportation and storage facilities that have made it possible for farmers to engage profitably in commercialized agriculture.

It is in the upgrading of administrative performance by local governmental and semigovernmental agencies and the improvement of institutional linkages and communications between village and city that the Saemaul Movement has probably made its greatest contribution. Pressures from the top to achieve rapid, concrete and dramatically visible results have been so great that in six years the mass of provincial, county and sub-county officials has been forced to change their outlook and working style from that of conservative, self-seeking, formalistic control and *status quo*-oriented bureaucrats to that of relatively enthusiastic activists dedicated to a transformation of the countryside. Their careers have been at stake. The highly centralized authoritarian political system of South Korea has proved to be well adapted for accomplishing this transformation, even though it has never been specifically enunciated as a goal of the Movement.

The Ministry of Home Affairs and its local agencies, the provincial, county and sub-county administrative offices, have generally exercised effective supervision, making sure that the efforts of various other concerned government agencies were integrated in the overall Saemaul Movement. After many years of "fragmented hierarchical programs" South Korea has finally achieved a coordinated administration of rural development policies. The implications for future rural development of such increased local administrative effectiveness are great. In addition there is now a recognition by villagers that technological advice, capital and improved marketing facilities can best be acquired through official channels and the expansion of ties with the national economy. Officials are no longer feared and avoided as in the past, and the social gulf between farmers and bureaucrats has noticeably narrowed.

Some persistent problems remain, however. The poorest farmers and laborers, who have no land or very little land and who make up about 15 to 25 percent of the rural population, are not particularly enthusiastic about the New Community Movement. They complain that while obliged to

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participate in village public works projects, usually without pay, they receive no benefits comparable to those of landowners whose property is being improved. They must live by their labor, and they insist that "voluntary" collective work is an unfair burden. Also, higher grain prices are of little help to the 40 percent of all farm households whose land holdings are so small that they have little or no marketable surplus.

The long run future of the Movement is somewhat problematic, because of a potential contradiction in values and organizational structure that is inherent in contemporary Korean society. The Movement's success (but not necessarily further rural development) depends on continuing community solidarity and cooperative effort at a time when individualism and materialism, both as personal ideologies and as patterns of economic behavior, are challenging tradition in every social sector. So far, although exceptions exist in most villages (particularly those near urban areas), traditional patterns of interaction reinforced by outside official support for collective organizations and cooperative effort seem to have resisted or contained the divisive effects of commercial individualism.

The CBIRD program to be described below began some two years after the start of the Saemaul Undong, and it has managed to embed itself within the Saemaul Movement, both at the village level and in terms of the local administrative environment. It is not possible to understand the CBIRD method of operation or evaluate its achievements without considering the general context of contemporary rural development in Korea as outlined above.

The CBIRD Concept and Goals

The Save the Children Federation/Community Development Foundation (SCF/CDF) of Westport, Connecticut, U.S.A. has been engaged since 1973 in an innovative, systematic, and highly organized effort to increase rural income and upgrade the quality of village life in South Korea. SCF/CDF, a nonprofit, sectarian, voluntary organization, has appropriately named its Korean program, "Community-Based Integrated Rural Development" (CBIRD). This general idea was first tried out in Korea, and later applied in more modest ways in 17 developing countries.

Save the Children Federation began its work in Korea in 1953 by providing aid to war orphans, widows and refugees. After 1957 when SCF established a Korean office of its newly created Community Development Foundation (CDF), its aid in the form of cash and relief goods was increasingly converted to self-help support. In order to increase family productivity, CDF encouraged and assisted farmers in the raising of livestock and the cultivation of cash crop vegetables. For the community as a whole there was support for such public works projects as land reclamation, bridge and reservoir construction, and improved sources of

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drinking water. From the start SCF/CDF encouraged the maximum amount of local participation and management in its development projects. By 1972 various kinds of assistance--to individuals, to families, and to communities--had been furnished to about 7,000 people in some 400 communities.

In 1972 SCF/CDF decided to consolidate the various programs, focusing its main effort on promoting integrated development in several clusters of cooperating villages that were called "impact areas." In June 1976 SCF/CDF received from the United States Agency for International Development (USAID) a sizeable grant in partial support of the Korea program. Under provisions of the grant CDF was expected "to establish pilot community-based integrated rural development projects as mini-regional (or small area) development management models, with an ultimate goal, over a five year period, of institutionalizing a process that will improve income, health, education, and community institutions and services for low income rural people." There are now six "mini-regional" projects, three island areas and three in the mountainous north central region.

There are three main aspects of the CBIRD concept that, when taken together, distinguish it from most other development efforts:

1) The term, Community Based Integrated Rural Development, represents an attempt to combine the strengths of traditional community development theory and methodology with the advantages of a larger scale, systems-oriented, carefully planned and integrated development strategy.

2) The unit of development or impact area comprises several villages, roughly corresponding to the lowest level of local government administration called the *myon*.

3) The CBIRD program is designed to supplement and be integrated with the *Saemaul Undong* program of the Korean Government.

The general scheme tries to profit from the insights and techniques of the hard-headed economist or systems analyst, while remaining true to basic community development principles. The community development approach has traditionally been people-oriented, with an emphasis on changing values and relationships within a small face-to-face community in order to get things moving. CD practitioners insist that development efforts should be directed at the "felt needs" of a community, and that this can only be achieved by maximizing local participation in decision-making--in the planning and direction of projects. Self help through cooperative effort and the investment of local resources is stressed. And finally there is usually an emphasis on egalitarianism and improving the quality of community life, particularly with regard

to the situation of the poor and other deprived groups. The economist's planned approach to rural development, on the other hand, usually involves both capital inputs and direction from outside the local community, in accordance with a large-scale plan that is more concerned with increasing quantifiable measures of production than with such intangibles as human motivation and satisfaction. The plan is formulated on the basis of more or less rigorous surveys and sophisticated economic and technological analyses of problems to be overcome.

The CBIRD concept combines what are regarded as the strengths of both methodologies. At the same time it recognizes that the actual program operation must take place within the political context of a highly centralized, authoritarian bureaucratic administration. The term, "integrated," in the CBIRD title, then, can be taken to mean that a variety of problems at the village level should be attacked simultaneously. In its theoretical formulations SCF/CDF places great emphasis on local decision-making, and self help. The creation of permanent local organizations capable of planning and implementing various kinds of development projects is regarded as just as important as the actual end results achieved by such projects. This process of "bottom-up" decision-making and management is believed to be superior to centrally planned and directed "top-down" systems imposed on farmers by bureaucrats from outside the villages for two principal reasons: 1) it is alleged that only grass roots participation in the entire process can ensure enthusiastic widespread involvement, a correspondence of project goals with locally felt needs, and an equitable distribution of benefits; 2) in the longer term after CDF capital and advisors are no longer available, local initiative and control are necessary in order to ensure that developmental momentum is maintained.

The "development management model" requires that villagers receive various kinds of training in order to be able to survey local needs themselves, assess capabilities, reach reasonable decisions and carry them out effectively. Accordingly the CBIRD projects all involve extensive programs of nonformal education. In addition to courses in leadership, planning, evaluation and agricultural (or fishing) technology, CDF also trains villagers to manage local credit unions and to operate a system of development loans through a revolving fund by which increased farm income is recycled into the local-village economy. While it is recognized that increases in productivity and income should probably have priority at the initial stages of a rural development program, CDF tries to attack all the major constraints on improving village life. Health care, nutrition, child care, family planning, sanitation, and social/cultural/recreational activities are as much a part of the overall design as projects designed to increase productivity and incomes. In particular, CDF has stressed that the CBIRD projects are designed primarily to assist the rural poor, with women and children singled out as principal beneficiary groups.

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These are all conventional community development goals. What is innovative about the CBIRD program is that it is organized to provide an integrated development approach for larger areas, comprising from six to twenty-one villages with populations of from 2,000 to 9,000 persons. There seem to be two main, interrelated advantages to increasing the size of the impact area: 1) It becomes feasible to undertake more ambitious projects in such sectors as public works, education (both formal and nonformal), and health care where large initial investments in trained personnel and facilities are usually required. Also, there is a much larger local resource base to support such projects, in terms of both labor and material contributions. 2) the "mini-regional" area corresponds roughly to the sub-county *myon*. The fact that the government cooperatives and extension service have local offices at the *myon* level is of great importance. Once a measure of consensus and a willingness to participate in achieving joint goals has been established beyond village boundaries within the impact area, then local leaders can work together with officials in formulating development plans and obtaining additional funding or other kinds of governmental assistance. Close collaboration with governmental administrative agencies and other outside institutions, both public and private, is an integral part of CDF's method in Korea. The integration of village economies with national markets, the introduction of the latest agricultural and fisheries technology, and the inculcation of efficient methods of local planning and financial management, all require close and constant ties with the more modernized sectors of Korean society.

The Implementation Record

The booming prosperity and industrialization of the urban areas and the rapid growth of the Korean economy have created unusually favorable conditions for development in both agriculture and fishing. Villages have been carrying on extensive self-help projects since 1972 within this favorable economic climate and there have been significant increases in living standards and agricultural productivity. Expectations for further progress are high, and there is a general acceptance of the need for innovative change. In contrast to the suspicion and hostility with which officials were regarded in the past, villagers now tend to look to local administrative agencies for advice and material assistance.

Environmental factors, however, vary a great deal. While the CBIRD areas all have considerable potential for development in terms of topography and arable land--or access to marine resources--the inland farming communities have certain advantages over the island fishing areas, at least at this stage. They are more homogeneous, both with regard to kinds of productive activity and the distribution of wealth. They are also more compact, comprising fewer villages, among which transportation is easier. Moreover, CBIRD programs were initiated in

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the mainland communities several years before the island programs. Some--probably most--of the difficulties encountered in the island projects are attributable to aspects of the physical environment or the lesser amounts of investment. In addition, the unfortunate tradition in Korea of contempt by educated city dwellers for fishermen, whose characteristics are contrasted unfavorably with the sturdy virtues of the farmer, still persists.

The CBIRD program has clearly made substantial progress in implementing its decentralized and leverage-utilizing financial strategy. Cumulative CDF grants to the six rural CBIRD areas through June, 1978 totaled $683,000 (excluding expenditures of the SCF/CDF field office in Seoul). Investments in CBIRD projects by the Government of Korea over the same period somewhat exceeded this amount. Community self-help investments and contributions of materials and labor totaled an estimated $1,500,000. (This figure, particularly the portion relating to contributed labor, is only a rough approximation and could be somewhat inflated.) Thus it appears that, overall, each CDF dollar has been matched by four to five dollars of local effort and government funds. These figures do not mean, of course, that in the absence of CDF grants and the CBIRD program none of the other investments would have been made. There is good reason to believe, however, that the CDF funds primed the pump for considerably larger efforts by others--especially the communities themselves--than would otherwise have occurred.

The impressive local effort shown above is partly explained by the fact that 40 percent of the CDF grant funds were recycled back into the local economy as loan assets (controlled by the Community Committees), against which local people can borrow for their own private productive and household improvement projects. An additional 34 percent went into physical property and facilities (e.g., the Community Centers) vested in the Community Committees. These growing assets, summarized for the six areas in Table 1, have given the Committees an increasingly stronger base of authority and viability. We can reasonably conclude from the above evidence that CDF's financing strategy, calculated to produce a multiplier effect on total investment funds for the CBIRD approach after CDF's withdrawal, has been quite successful.

It is instructive to compare the FY 1978 record of one of the early mainland CBIRD areas, Chunsong, and one of the later island areas, Yaksan, in terms of their mix of planned projects and the extent to which they were implemented.

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TABLE 1

Community Assets Created by CDF Grants as of 1978 (in U.S. dollars)

	CDF Grants	Community Committee Property	Revolving Fund Loan Assets
Sanbuk	185,135	78,703	70,157
Yanggu	167,131	68,112	58,894
Chunsong	125,042	63,027	48,422
Wido	74,552	—	29,923
Yaksan	76,639	6,570	38,417
Jeungdo	74,224	17,671	42,931
Totals	683,323	232,083	284,544

Chunsong. The projects planned for the Chunsong area for FY 1978 and the extent to which they were actually implemented are shown in the first two columns of Table 2. The next three columns show the relative investment of CDF, Community, and Government funds in each project. Out of a total investment of $94,800, CDF grants accounted for $29,400; community effort $53,400; and Government contribution $12,000.

The annual plan as depicted in Table 2 originally provided for six productivity/income-raising projects and five social infrastructure projects. Two important modifications were later made, however. The project for building 20 tobacco drying houses was dropped because, even though local farmers had been heavily and profitably engaged in tobacco growing, increased problems with plant disease and falling prices convinced them that other crops would be more profitable in the long run. Hence, some of the funds earmarked for the tobacco houses were redeployed to irrigation pumps to counter the adverse impact of the 1978 drought on cash crops. The striking fact is that, according to the year-end report to CDF, all the remaining 10 projects (except for Health and Sanitation) achieved or exceeded their planned targets during the year--an impressive record.

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TABLE-2

Implementation Record of Chilnsong CBIRD Projects FY 1977-78

Projects	No. of Projects Planned	No. of Projects Actual	Actual Investments (US$) CDF	Community	ROK Govt.
Tobacco drying houses	20	0[1]			
Cows	10	10	4,158.	6,757.	
Cow pen construction	10	15	6,237.	9,338.	
Vinyl greenhouses	10	10	3,534.	6,362.	94.
Community center	ongoing	1 center	2,798.	1,040.	
Leadership training courses	18	18	595.	688.	
Day care centers	ongoing	4 centers	2,524.	4,368.	8,220.
Education & culture	8	10	2,144.	1,331.	
Health & sanitation	4	1	1,247.	7,445.	
Irrigation pumps		19[2]	2,219.	3,169.	561.
Administration			1,341.		
Totals			27,072.	40,492.	8,875.
Locally Supported Projects[3]					
Garlic planting	2 ha	4.2 ha		10,395.	
Truck purchase (co-op)	1 truck	1 truck		2,079.	8,316.
Women's Welfare Bank	1 bank	1 bank		1,208	
Totals			27,072.	54,172.	15,191.

[1]Cancelled; see explanation in text.

[2]Added; see text for explanation.

[3]Defined as "projects not utilizing SCF/CDF funding but which resulted directly or indirectly from SCF/CDF's assistance or involvement."

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The emphasis of the Chunsong program is revealed by the allocation of expenditures. Two-thirds of the total expenditures went into economic projects, principally cattle raising, vinyl greenhouses for cash crops, garlic planting and purchase of a truck, reflecting a strong local preference for income-producing projects. Within the social infrastructure category the largest expenditures were for operating the four existing day care centers for children, a health and sanitation project, and the operation of the Community Center, all of these reflecting CDF priorities. Smaller amounts went to leadership training, education and culture, and administration.

Yaksan. This island area presents a quite different pattern than Chunsong in FY 1978. As shown in Table 3, the plan provided for 10 basically economic projects representing a wide assortment of activities (e.g., animal raising, vinyl greenhouses, growing medical herbs, kelp and seaweed, planting fruit trees, an abalone nursery, and an irrigation channel). The 12 planned social infrastructure projects were equally varied. They included, for example, building a community center, a public bathhouse, a consumer cooperative store, a road and ferryboat landing, kitchen and roof improvements on private homes, school supplies and equipment, athletic and cultural events, health (parasite extermination), and leadership training.

The actual implementation record was considerably poorer than Chunsong's. Of the 21 planned projects only ten met their target, five fell short, and six were delayed or cancelled; but four small unplanned projects were added. In the circumstances, however, this was actually not so bad a record. The CBIRD program in this area, after all, was quite new and the management inexperienced; expected government funds for some important projects failed to materialize; the drought upset certain other projects; competing Saemaul projects diverted funds and energies; market conditions for some agricultural products declined, and popular interest in certain projects evaporated. Despite all these problems a total of $240,000 in cash and in kind was invested during the year, including $39,900 of CDF funds, $75,900 in local resources, and $108,100 in government funds and materials. The largest single expenditure was on re-roofing houses ($24,000); the main agricultural projects together took $35,000, and public works over $11,000. Less than $5,000 was devoted to social welfare. (It is pertinent to note that the population of the Yaksan area is 9,058, compared to 2,108 in Chunsong.)

Some Lessons and Open Questions

Since 1971 the pace of change in virtually all of South Korea's 36,000 villages has picked up dramatically, as village economies have become more and more tightly integrated with that of the nation as a whole, and as bureaucratic influences on almost every aspect of farm

Table 3

Implementation Record of Yaksan CSIRD Projects FY 1977-78

Project	No. of Projects Planned[1]	Actual[1]	Actual Investments (US$)[2] CDF	Community	ROK Govt.
Animal Raising			5,925.	6,993.	
Cows	35	3			
Goats	100	50			
Pigs		60			
Medical Herbs (stavia)	.02 ha.	.02 ha.	1,683	3,748	
Consumers Co-op Store	1 store	1 store	1,040	948	120
Vinyl Greenhouse	0.3 ha.	0.2 ha	624	249	
Kelp Cultivation	3.0 ha.	delayed	4,158		
Women's Sub-committee	(various projects)		1,040	2,721	
Community Center	construction planned	delayed	5,489		
Kitchen Improvement	30	30	624	938	
Abalone Nursery	2 ha.	cancelled			
Irrigation Well	not planned originally	½ acre irrigated	624	959	
Leaders Training			2,079	1,372	
Athletic & Cultural Events	cancelled because of drought				
Roof Improvement	41 houses	41 houses	6,819	17,384	
Seaweed (laver) Cultivation	1 nursery	1 nursery	2,079	6,237	2,079
Public Health	Parasite Extermination		1,040		1,040
Housing	30 houses cancelled				
School Supplies	Books & drawing materials		624		624
Telephone Line	1	1	520	21	
Public Facilities	bath house village hall	cancelled			
Road Construction	100 m.	100 m.	416	499	
Water Tank	not originally planned	1 tank	624	895	
School Drinking Fountain	not originally planned	1 system	2,017	1,490	
Administration			2.495		
Locally Supported Projects					
Fruit Tree Planting	3,000 persimmons	3,000 persimmons		5,884.	
Irrigation Channel	400 m.	300 m.		1,238.	624.
Ferry Boat Landing	1500	150 m.		labor	10,400.
TOTALS			39,900.	51,555.	14,847.

[1]Additions and cancellations of projects explained in text.

life has deepened. From this standpoint the CDF program must be seen as an effort to fine-tune and accelerate the process in a few carefully selected areas. CBIRD has supported the Saemaul efforts but has gone beyond them, enabling farmers, fishermen and others in its impact areas to exercise a greater degree of control over their development process. While one general effect of both Saemaul and CBIRD initiatives has probably been to reinforce local producers' dependence on outside institutions and the linkages with the national economy, the CBIRD approach has clearly demonstrated better ways to plan, finance, and direct further progress in accordance with villagers' own goals and needs. It has furnished the multi-village area with a set of institutions and a methodology that enables the local population to make the most of their available resources. Most importantly it provides them with a workable means of acquiring those essential factors of production that are everywhere in short supply: capital, technical know-how, and management skills.

So far, particularly in the mainland impact areas, the CBIRD initiatives have produced impressive results in increased productivity, incomes, and local living standards. On the islands there have been some initial problems and delays, but a wide variety of projects is now being implemented, and given that some of the island programs represent much smaller per capita investment by CDF, the benefits already achieved are significant.

It is not possible to reach any firm conclusions regarding the extent to which successful CDF programs in Korea are replicable in other countries. Nevertheless, it seems useful to raise some leading questions to establish a comparative basis for exploring possibilities.

There can be no doubt that four factors in the Korean environment of the 1970s--the relatively equitable distribution of land holdings, the profitable and expanding markets for agricultural and fishery products, the high value traditionally placed on education and learning in the Korean culture, and the aggressive promotion of rural development by the government--have all contributed importantly to the effectiveness of the CBIRD program. It would seem to follow, therefore, that the absence of any one or combination of these positive factors in another country setting--especially a very low income country with a low economic growth rate--would constitute a serious impediment to replicating the successful CBIRD experience in South Korea.

Concerning the results of CDF's concentration on areas with a "good potential for development," we can give only a speculative answer. CDF was undoubtedly well advised to choose such promising areas as Sanbuk and Chunsong in which to launch its experiment because it required testing out a complicated and untried approach that would

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inevitably present sizeable problems and risks even under relatively favorable circumstances. To have started with the hardest cases could well have doomed the experiment to failure from the outset. In moving on from these initial areas to the island areas of Wido and Yaksan, CDF did indeed take on some relatively "harder cases." Yet even these areas had a good deal going for them, especially in terms of prospering markets and rising prices for marine products, and the availability of substantial local savings—albeit concentrated in relatively few hands—for reinvestment in development. There are, however, some much "harder cases" in Korea, particularly isolated mountain villages with only poor to moderate development potential and still lying outside the mainstream of the dynamically growing Korean economy. It is reasonable to suppose that if the CBIRD approach were now to be tried out on some of these truly "hard cases" it would encounter much greater difficulties and would probably have to be modified in some ways to achieve significant results.

This observation is not intended to imply that the CBIRD approach and the lessons of its experience in South Korea have no relevance to less prosperous countries. No one can really know until it has actually been tried. What is very clear, however, is that CBIRD's unusually favorable environment in South Korea, especially the extraordinary economic dynamism, cannot readily be replicated elsewhere, so that expectations of what a modified CBIRD approach might achieve under much less favorable economic circumstances should be appropriately modest and realistic.

The discrepancies between CBIRD's more intangible goals concerning social change and welfare and the actual program accomplishments pose a few important unresolved questions that merit review, especially since they apply in many countries.

Can the poor really be helped? Most of the benefits from CDF investment accrue to middle-level and well-off farmers. Relatively little can apparently be done to change this pattern, despite the best intentions and efforts on the part of the CDF staff and Coordinators. In the Korean case it seems evident that except for outright charity, attempts to help the poorest sector of the rural population must depend mainly on the trickle-down effect of generally increased village prosperity. The goals of restructuring society so as to change the distribution of wealth, and of establishing a new welfare-oriented mentality among local elites, are simply beyond the capacities of the CBIRD program—or any other program for that matter, short of a thoroughgoing political revolution.

The question then inevitably arises: given a widespread international donor consensus on the need to improve the lot of the rural poor, to what extent is this goal really practicable? Perhaps there

is something wrong with our perceptions of the problems. Have we taken adequate account of the very solid and durable social/structural obstacles to the kinds of change that are so widely regarded as desirable? Or, to put the matter in terms of practical strategies, is it possible to redistribute wealth or focus efforts mainly on aiding the poor, while at the same time promoting self-sustaining rural development? We must conclude here that, in Korea at least, the answer seems to be no. Our assessment of the CBIRD programs suggests that, regardless of its statements of basic principles and objectives, SCF/CDF—in its actual operating procedures—has implicitly reached the same conclusion.

Unless a rural society is in a state of chaotic demoralization or upheaval, which has not been the case in South Korea, an effective integrated development program must be based on existing traditions, values, and institutions. It may be possible to modify their operation in gradual and subtle ways, but if the change agent's commitment compels him to confront and try to do something all at once about such intractable problems as the role of women, child-rearing practices, village authority structures or hierarchies of wealth and status—all in addition to technical agricultural innovation—then truly his program's failure is assured. In Korea, at any rate, effective self-help efforts depend on strengthening and improving village institutions and leadership in accordance with generally recognized, traditional standards—not on undermining or radically transforming them. A community worker can never afford to lose sight of the social mechanisms through which people interact and organize their group efforts, no matter how dedicated he may be to certain overriding objectives.

CDF Coordinators and Community Committees have arrived at reasonably successful compromises on the choices between health and welfare versus income gains in the actual working out of a viable mix of projects in the impact areas. The social welfare effort has been concentrated mainly on women's training, day care centers, and actions to reinvigorate and supplement existing family planning programs. Except for the day care centers, however, the amounts invested have been minor compared to other kinds of projects. Another lesson here, then, is that if "bottom-up" participation and decision-making has any meaning, it is that under the CBIRD approach local leaders will determine the direction that development takes in accordance with their own (and the local administration's) ordering of priorities. Any serious effort by donors to alter local priorities would be self-defeating, which is to say that any major direct effort to improve the lot of the landless and helpless poor will have to wait.

Will villages work together? Another major objective of the CBIRD system has been the formation of multi-village communities as the focus for development efforts. Here it is useful to make a distinction be-

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tween a true sociological community and a set of villages that are able to plan and work together under unified leadership for mutually agreed upon goals. Only in Sanbuk does there appear to be a strong and broader sense of community in which feelings of mutuality and social responsibility--a concern for the common welfare--go beyond village boundaries to encompass the whole impact area. The impression is inescapable in Sanbuk that farmers not only participate energetically, they also take pride in operating the CBIRD machinery for their own purposes. This same sense of proprietorship is popularly reflected in the frequent, everyday use of the Community Center. In the other CBIRD areas the same general formula is being followed, and there is widespread and grateful recognition of the benefits derived from it. But for most people the activities remain something that is being done for them by outsiders in accordance with externally imposed rules and procedures. In terms of their associations, loyalties and economic goals people continue to identify themselves with a particular village or kinship group. Or, where such ties are weakened, they are likely to migrate to the city.

The idea of the natural village community as the focus of social life and (now) of developmental aspirations is deeply ingrained in Korean mentality. Intimate, long term personal association is regarded as the proper and natural basis for both rural leadership and cooperative effort. Accordingly the Saemaul organizers, while recognizing the importance of planning and coordinated effort on a regional basis, have continued to emphasize the individual village, both as the local decision-making unit and as the basis of labor mobilization. Coordination of larger projects beyond the village level is regarded as the function of local administration. Is it likely that the demonstrated effectiveness of the CBIRD methodology will change official thinking on this issue? On the basis of the present study it seems highly problematical. In the longer run, however, the prestige, authority, and ubiquity of Korean governmental agencies will determine the form and manner of operation of all local institutions.

What are CBIRD's long term prospects? Today the social and economic horizons of Korean farmers are rapidly expanding, and CBIRD projects are accelerating the process. Local leaders are actively participating in guiding the development of their communities. But the Korean Government depends on the docile support of the rural population. It does not look kindly on the formation of any independent, private associations at the local level that might be in a position to challeng the authority of official agencies or serve as a rallying point for demands for greater local autonomy. It would be highly misleading to assume, as some have done, that the organization of local decision-making for economic development represents a significant trend in the direction of grass roots political democracy. Korean tradition, current governmental practice, and the geo-political situa-

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tion in Northeast Asia all oppose such a tendency, at least in the forseeable future.

Thus it seems unrealistic to expect that a set of model or pilot communities implanted in Korean rural society can eventually transform that society by example in accordance with a particular ideal vision. Rather it is the other way around. As CDF phases out its operation, the model will inevitably be transformed by the particular conditions and popular attitudes of each area and by the ubiquitous and growing influence of the bureaucracy.

At the time of this case study discussions were reportedly going on at high levels in the Korean Government with a view to restructuring the cooperative system to achieve a greater degree of active local participation and greater responsiveness to local needs. Were this to occur, the national organization would then play more of an advisory and facilitating role than, as at present, a stronghanded directive role as executor of government policy. In such a climate, the seeds of local planning, management and self-help that CBIRD has planted and nurtured would have a real chance to thrive. Whether such a vision is utopian or not, it appears to us that the local cooperative is in fact the logical focus of integration and the most promising successor to CBIRD. In any event, there can be little doubt that in the long run the CBIRD innovations will leave some useful and enduring impacts on the Korean rural scene. But just what form they will take and how extensive they will be, only time can tell.

[Edited extract from Meeting the Basic Needs of the Rural Poor: the Integrated Community-Based Approach, Philip H. Coombs, Editor, pp. 534-39, 528-32, 576-83, and 327-34. Copyright© 1980, Pergamon Press, Oxford, England.]

Note: The book from which this article was extracted contains nine studies on ways of meeting basic needs of the rural poor, and can be ordered for $15.00 (prepaid) from:

International Council for Educational Development
Box 217, Essex, Connecticut 06426
U.S.A.

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PLANNING AND EVALUATING EXTENSION PROGRAMS

I. Introduction

PROGRAM DEVELOPMENT in the Cooperative Extension Service involves three major functions: first, determining what the program will be —planning; second, carrying out the plan—implementing; and third, checking up on accomplishments—evaluating.

Program development in Extension is a continuing series of interrelated processes which result in the accomplishment of the educational mission and objectives of the organization. It includes organizing to accomplish the mission, determining the content of the program, setting priorities and stating objectives, developing plans to accomplish the objectives, implementing the plans, evaluating and reporting results, and using the results in planning subsequent programs.

It is a continuing series of processes operating within the programming framework. These processes are presented schematically in Figure 1 and include the following:

1) Development of the institutional policies or framework for program development.

2) Organization among the staff for program development.

3) Program determination—the long-range Extension program document.

4) Program strategy—the annual plan of work.

5) Program action—implementation of the program.

6) Program evaluation — accomplishments of the program.

This publication should serve as a guide to Extension agents at all levels in the theory and practice of planning and evaluating Extension programs. The concepts apply to all of the educational programs conducted by the Cooperative Extension Service. Specifically, a practical approach is presented for developing the annual plan of work. The evaluation concepts presented apply not only to the broad process of evaluating long-range programs and annual plans of work, but also to all types of Extension educational programs whether large or small, long-range or short-range.

Extension agents in a very real sense are change agents. To be effective in bringing about change with Extension clientele, there should be a foundation of practical concepts on planning and evaluating. This publication is intended to help in this regard.

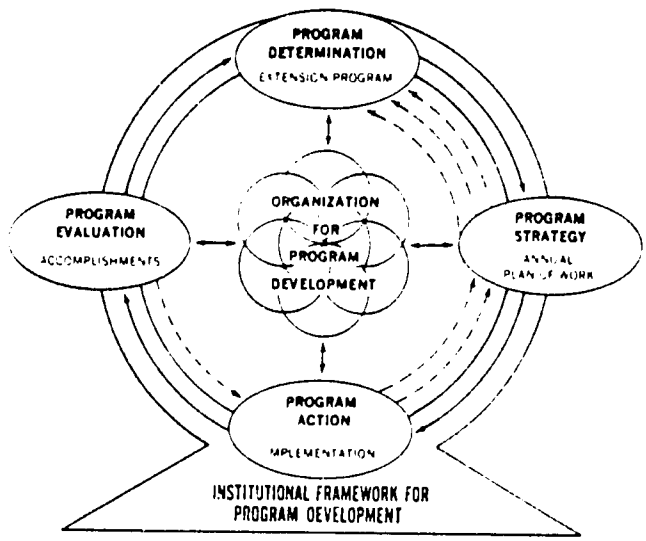

Figure 1. Processes of Extension program development.

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II. Planning Extension Programs

Program planning begins with Extension's clientele—PEOPLE. It ends at the national level, and all along the way a series of events—each important to the process—must take place. Ultimately, the process results in effective plans for Extension's efforts at the county, state, and national levels.

The planning process results in written plans of work at county and state levels within the Extension organization. Written plans are of two types: first, the long-range program which is a broad projection of the Extension program for a period of 3 to 5 years or more; and second, the annual plan which sets forth the specific Extension effort for a 1-year period. In either, the plan of work is intended as a guide or roadmap for agents and leaders to follow in fulfilling effectively the Extension educational mission. In addition, properly prepared plans are an ES-USDA requirement for release of federal funds to operate the Extension program.

STEPS IN PLANNING

Step 1. THE COUNTY PLAN OF WORK.

A prerequisite to planning is staff unity. The staff must be together on how the plan will be developed. This implies a common understanding of the tasks involved and agreement on who will do what. There must be "planning for planning" among the staff. Agents must be assigned leadership responsibilities with the various commodity and special interest committees of the county Extension council.

There must be coordination so that the total staff understands generally what is going on. Priorities must be set. Dates for meetings of the staff and council must be determined and an agreed-upon plan for training council members must exist.

Agents, not the council, are responsible for writing the county plan of work. To do this, they must have an opportunity to *listen* to evidence from at least three sources on what should go into the plan.

Source 1—THE PEOPLE. Representatives from the people should be organized into an active county Extension council. The council should be made up of committees in the areas of Agriculture and Natural Resources, Home Economics, 4-H and Youth, and Community Resource Development for the purpose of expressing their viewpoints on the problems and opportunities which need attention in the plan of work.

Source 2—SPECIALISTS AND RESOURCE PEOPLE. Agents should listen to the appropriate experts for trends and projections based on new research applicable to local situations. Valuable information can be gleaned from local agencies and organizations, both public and private, who may not be a part of the council. This information should be discussed by the agents with the county Extension council committees as deliberations are made on the content of the county plan of work.

Source 3—THE ENVIRONMENT OR WORK SETTING. There are definite indicators in the environment or work setting that agents should consider in developing the plan of work, such as crop and livestock opportunities, social and economic living conditions, community services and facilities, employment, health and age characteristics, natural resources, etc.

When the evidence is all in, agents are in a position to write a county plan of work that identifies the important priorities. A guide for writing the plan follows later in this publication.

Step 2. THE SPECIALIST PLAN OF WORK.

Specialists at the area and state levels develop plans of work according to their staff-group functions. They, too, need to *listen* to inputs from at least three sources before putting their plan into written form.

Source 1—THE COUNTY PLANS. If the processes described in Step 1 are properly followed by the county staff, then specialists are easily able to summarize county plans and determine the greater portion of the specialist plan. The audience for the specialist is also the PEOPLE. The process of planning involves making decisions on how best to join hands with the county staff to serve their needs.

Source 2—RESEARCH FINDINGS. The major function of the specialist is to stay closely attuned within subject matter disciplines to research findings at land-grant and other institutions and to make this information available to the county staff through publications, newsletters, slide sets, and other practical methods. Making research results known to agents is the central focus of the specialist's plan of work.

Source 3—THE ENVIRONMENT OR WORK SETTING. The technical nature for some subject areas suggests that specialists can best serve clientele needs on a direct basis. These areas provide indi-

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cators for objectives which should be included in the specialist's plan of work and coordinated with the county staff.

Step 3. THE STATE PLAN OF WORK.

The state plan of work involves organizing plans for the county and specialist staffs into areas of Agriculture and Natural Resources, Home Economics, 4-H and Youth, and Community Resource Development. The plan also includes a section on administration, which outlines essential administrative functions. This document then becomes the guide or roadmap on a broad scale for the overall organization. It is here that statewide goals and objectives are found.

All states submit their state plan of work to ES-USDA in Washington which then gives direction to the national Extension effort.

WRITING THE PLAN

The written plan of work for each commodity or area of emphasis should contain five sections, each essential and interrelated to the others. These include (1) the situational statement, (2) objectives, (3) methods, (4) expected results, and (5) evaluation techniques. All sections tie together in that the situational statement outlines base data about specific *problems and opportunities* for a given commodity or area of emphasis. The objectives specifically state *what* clientele hope to do about the conditions which exist. The methods section outlines *how* the objectives will be accomplished with the use of appropriate teaching techniques. Expected results relate to *target numbers* and/or *percentages* agents have in mind, and finally, evaluation techniques are listed to determine *degrees of accomplishment*. All five sections work together with no single one able to stand alone. A closer look at each of the five sections follows.

Section 1—THE SITUATIONAL STATEMENT. The situational statement is exactly what the term implies—the "what is" or status. It is a written survey of the commodity or area of emphasis which pinpoints existing problems and opportunities. It is also a data bank containing basic statistical information to support the validity of the problems and opportunities identified. The situational statement provides a justification for objectives and a basis for establishing priorities.

The long-range program situational statement should be elaborate, containing a complete analysis of problems and opportunities for several years. The annual plan of work should pinpoint only those problems and opportunities which will be worked on during the current year.

Section 2—OBJECTIVES. Educational objectives state what the learner or client hopes to do about the problems and opportunities in the situational statement. Objectives should be people-oriented, not agent-oriented. It must be possible at some point in time to look at objectives and determine whether or not they were accomplished. Some objectives can be accomplished in a 1-year period or a shorter span of time. Others may take several years to reach.

Objectives are statements of intent involving three parts:

1) Identification of the *audience* (clientele) to be reached,

2) Identification of the *subject* (information or content) to be taught,

3) Identification of the *change* (end results) that is desired by the audience or clientele—often called a behavioral change. An educational objective can be thought of as a *gap*—a gap between "what is" and "what could be." It is a statement of intent for progress.

"WHAT IS" —— OBJECTIVE —— "WHAT COULD BE"

Figure 2. A simple model defining objectives.

Objectives set goals for learning. One definition of learning is "a change in human behavior through new experiences." Changes in human behavior can either be new *knowledge*, new *skills*, or changes in *values*. Knowledge relates to acquiring and understanding information. Skills relate to learning to do something which requires the use of the hands, arms, feet, legs, or some portion of the body. Values relate to a person's attitude, what he or she feels to be important, or inner feelings. Objectives in Extension programs may deal with one or all three. Objectives which deal with values are harder to attain because it takes time, often many years, to change attitudes or feelings.

Examples of changes in behavior may be:

KNOWLEDGE—For peanut producers to acquire and understand the latest research findings from the Wiregrass Experiment Station.

SKILLS—For 4-H Club members to participate in the automotive program to become safer and better informed drivers.

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VALUES—For homemakers to adopt home freezing as an improved method for food preservation.

Objectives can be either specific or rather broad in nature. Time plays the major role in determining the specificity of objectives. Long-range programs contain broad objectives attainable over a 3- to 5-year span of time and frequently longer. Objectives in the annual plan should outline specific situations to be addressed during the year.

Long-range objectives state the "big picture" or goals. Many annual objectives are often necessary to reach a single long-range objective. Agents should plan annually only those objectives that are possible to attain in a 1-year time span, keeping in mind that annual objectives add up, hopefully, to attaining long-range objectives.

Long-Range Objectives (3 to 5 Years)	*Annual Objectives (1 Year)*
*1. For beef cattle producers to adopt recommended management practices to increase their calving percentage by 10 percent.	*1. For beef cattle producers to adopt pregnancy testing as a means of increasing calf crop percentage.
*2. For soybean producers to adopt recommended practices to raise per-acre yields to an average of 32 bushels.	*2. For soybean producers to adopt soil testing as a means of increasing per-acre yields.
*3. For homeowners to adopt recommended energy saving practices to reduce home energy requirements by 20 percent.	*3. For homeowners to adopt a 10-point recommended system of electrical appliance energy conservation in the home.
4. For 4-H'ers to gain knowledge and skills in leadership development to assume responsible leadership roles in society.	4. For 4-H'ers to obtain knowledge and skills in public speaking to develop leadership abilities.

*Objectives which specify the adoption process take into account the behavioral changes which occur with the acquisition of new knowledge and/or skills and attitudes.

Section 3—METHODS. Educational methods are the teaching techniques or "tools of the trade" that agents use to reach objectives. This is the section of the plan of work where activities, demonstrations, and events show up. A rather detailed listing of specific meetings, demonstrations, T.V. and radio programs, circular letters, and special events should be spelled out. Each method listed should tell *what* is to be taught as well as *when* and *where* it is to be done.

The methods section provides a sound basis on which agent performance evaluation can be made. Often circumstances beyond the control of agents will occur, such as unusual weather conditions, sudden shifts in economic conditions, insect infestations, etc., which prohibit accomplishment of objectives. But if agents are able to show that they carried out all the educational methods listed, then evidence is available which attests to the agent's efforts.

Section 4—EXPECTED RESULTS. Objectives are written in terms of what clientele hope to do. Methods are tied to objectives and outline the teaching techniques that agents plan to use to reach clientele objectives. Expected results are tied directly to the methods section. For the methods listed, what are the expected results? It is here that numbers and percentages show up regarding how many you hope to reach and what specific changes you expect to occur with the methods used. This section of the plan of work can be thought of as a listing of specific outcomes that agents are shooting for.

The expected results section also provides a basis for evaluating agents' performance. In one sense, this section provides agents the opportunity to set specific objectives of their own compatible with the objectives set for clientele.

Section 5—EVALUATION TECHNIQUES. Evaluation techniques are tools for determining whether objectives were accomplished or the degree of accomplishment. They also help determine whether or not expected results are reached. Evaluation techniques include such things as mail questionnaires, personal interview schedules, all kinds of distributed questionnaires and checklists, group interviews, case studies, systematic observation procedures, and studies of result demonstration records.

In selecting the evaluation techniques to use, agents should analyze each one to see whether or not it will provide the valid and reliable information needed. The most important consideration is to be sure that the evaluation technique provides a reasonable measure of the degree to which objectives and expected results were accomplished.

III. Evaluating Extension Programs

"Evaluation is a state of mind in which an Extension worker wants better information about his or her work and uses the information to make the work more effective. It is an investment which produces progress and growth in achieving the objective for which an organization has been set up."

This quotation makes a good text for this section on the evaluation phase of program development. *The first major point is that evaluation is part of the program planning process, not an afterthought.* In fact, evaluation may be poorly done or impossible to do unless it is built into the program from the beginning. If an objective in a program is fuzzy or too general to have any specific meaning, then the evaluation will be fuzzy or too general to be of much value in making decisions about the program. Think of objectives and expected outcomes as the two ends of a program, as indicated in Figure 3.

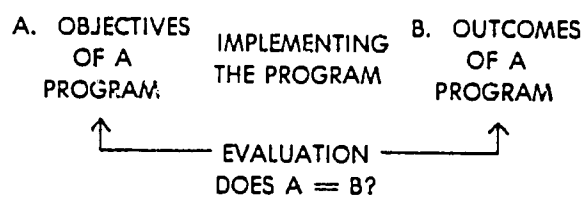

Figure 3. A simple model defining evaluation.

A second major point is that evaluation is needed to help the Extension worker make better decisions. Evaluation furnishes facts and understanding for decision-making. Frequently, input concerning the effectiveness of a program serves as a basis for making decisions about its future. To get this information, some research must be done. For example, questioning participants to learn if they got the expected benefits. Or, if there were not as many participants as expected, information is needed for the non-participants you wanted to become active.

Evaluation in Extension is not a new idea. Score cards and other evaluative devices have been used for many years. More recently, evaluation techniques have been used in Performance Reviews and similar personnel evaluation. When evaluation gets tied to accountability, everyone involved gets concerned about the outcome!

The major purpose of this section on Evaluation is two-fold:

1) To explain the principles and theory underlying evaluation of educational programs.

2) To apply these principles and theory to ACES programs.

In thinking about this two-fold purpose, it will be helpful to examine your assumptions about evaluation—not only what you know and understand about it, but also your feelings about it. Evaluation is sometimes threatening to people who are responsible for a program. One approach, or model, for the evaluative process will be outlined in some detail. And an application of this model to ACES programs will follow.

PRINCIPLES AND THEORY UNDERLYING AN EVALUATION PROGRAM

What is evaluation? Basically it is a judgment of worth—an appraisal of value. To think about something is often to evaluate it in some way. Everyday language is full of descriptive adjectives connoting value and judgment, such as beautiful, ugly, good, bad, too high, useless.

A more research-oriented definition would include a *rationale* for evaluation of educational programs. Heavy emphasis would be placed on decision-making and getting information needed by the decision-maker in an educational program. Here is the rationale:

1. The quality of programs depends on the quality of decisions about the programs;

2. The quality of decisions depends on the decision-makers' abilities to identify the alternatives which make up decision situations and to make sound judgments of these alternatives;

3. Making sound judgments requires timely access to valid and reliable information about the alternatives;

4. The availability of such information requires a systematic way of providing it; and

5. The processes necessary for providing this information for decision-making collectively comprise the concept of evaluation.

Evaluation based on this rationale is a way of providing information through research for making rational judgments in decision situations. A *decision* is a choice among alternatives. *Judgment* is assigning values to alternatives.

To provide information for decision-making, some organization of effort is needed. One approach is to see this as four functions:

1. Collecting information.
2. Organizing information.
3. Analyzing information.
4. Reporting information.

Of course, one must know what information needs to be collected. That is decided as a part of the plan for evaluating and will be shown clearly in the CIPP Model, below. Whether the information is adequate can be determined by raising the following questions:

1. VALIDITY. Is the information reproducible?
2. TIMELINESS. Is the information available when the decision-maker needs it?
3. PERSUASIVENESS. Does the information reach all decision-makers who need it?
4. CREDIBILITY. Is the information trusted by the decision-maker and those he serves?

Finally, the functions of decision situations in educational programs are *planning, programming, implementing* and *recycling.*

THE CIPP MODEL

To get the information needed for making rational decisions, you need a systematic plan. The CIPP Model is one approach that can be a valuable guide for Extension workers. It means getting information as follows:

1. CONTEXT—the situation or environment.
2. INPUT—the resources or restraints.
3. PROCESS—the design or methods.
4. PRODUCT—the outcomes or effectiveness.

The following tables and charts may be helpful in using the CIPP approach in evaluating educational programs.

THE CONCEPT OF CIPP IN EVALUATING EDUCATIONAL PROGRAMS

The proof of the pudding is in the eating.

It's results that count.

Or, on the other hand:

Do the job right and you don't have to worry about results.

Which line of thinking do you follow? Either way, sooner or later we need to take a closer look at the results as well as the processes followed—and at least occasionally at the objectives of the program. And, some are saying that we must go even further and examine the assumptions underlying the objectives! The CIPP approach helps us take a look at these areas in evaluating an education program. Here is a brief summary of this approach.

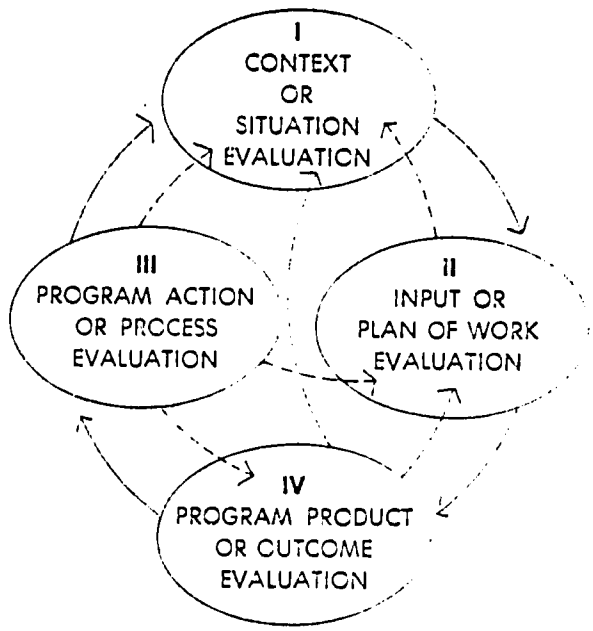

Figure 4. Four categories of evaluation for educational programs.

1. CONTEXT Evaluation (Objectives)
   Helps establish program goals and objectives.
   a. Describe the *situation* where changes are to occur.
   b. Identify *needs* that might be met by the program.
   c. Identify *problems* in meeting the needs.
   d. State *goals and objectives* of this particular program.

   • Key Question: How does the actual compare with the desired?

2. INPUT Evaluation (Strategies)
   Helps decide whether outside assistance is needed for meeting goals.
   a. Identify *resources and capability.*
   b. Develop *alternative solutions.*
   c. Develop plans, including strategies, for *implementation.*

   • Key Question: How well did the strategies work? Why?

3. PROCESS Evaluation (Procedures)
   Helps detect or predict defects in procedures for implementation.
   a. Clarify *procedures* (steps) followed.

b. Identify *barriers* or defects.

c. Check *feedback* and its use.

•Key Question: What did the program do that produced the desired results?

4. PRODUCT Evaluation (Results)

Helps analyze outcomes and relate them to objectives.

a. Describe *outcomes.*

b. Relate to *objectives* (intended outcomes).

c. Describe other outcomes *(by-products).*

d. *Interpret* findings.

•Key Question: Exactly how did we do?

APPLICATION OF PRINCIPLES AND THEORY TO ACES

Evaluation of Extension programs differs from some other educational programs. For example, paper and pencil testing in a classroom setting is usually not appropriate. The outcome hoped for in an Extension program is to be found in a real life situation in the home, in the community, or on the farm. Has the participant changed his or her way of doing certain things in everyday living? Whereas, the teacher in the classroom may evaluate the student by a test which may have little or nothing to do with what the student does at home.

Another related area in which the Extension worker may have difficulty in evaluating a program is the uncertainty of the clientele; for example, with a radio or TV program. Although the program may be planned for a specific type of audience, it is difficult to identify the actual listeners and get evaluations from them. Again, this contrasts sharply with the classroom teacher who has a role with everybody listed and knows who is listening—or at least who is present!

These difficulties can be overcome, but the Extension worker must be aware of the problems involved in evaluating informal educational programs. Furthermore, the limits of evaluating such programs need to be recognized and built into the objectives of the program. You should know that this may mean a more modest statement of objectives. For example, for the county Extension worker to expect everybody in the county to participate in a program is unrealistic and has no place in a planned program.

One way to modify immediate expectations, yet not lose sight of larger objectives, is to make objectives either short-range (1 year) or long-range (3 to 5 years). Statements of objectives must be fairly specific if evaluation is to be worth anything in improving this or similar programs.

The design for the evaluation of a program is extremely important. Even a simple evaluation of a small project needs careful planning if the evaluation is to be worthwhile. The two models on the following pages have specific suggestions to serve as guidelines for designing an evaluation project.

DEVELOPING EVALUATION DESIGNS

The logical structure of evaluation design is the same for all types of evaluation, whether context, input, process, or product. The parts, briefly, are as follows:

1. Focusing the Evaluation

a. Identify the major level of decision-making to be served: e.g., local, state, or national.

b. For each level of decision-making, project the decision situations to be served and describe each one in terms of its focus, criticality, timing, and composition of alternatives.

c. Define criteria for each decision situation by specifying variables for measurement and standards for use in the judgment of alternatives.

d. Define policies within which the evaluation must operate.

2. Collecting the Information

a. Specify the source of the information to be collected.

b. Specify the instruments and methods for collecting the needed information.

c. Specify the sampling procedures to be used.

d. Specify the conditions and schedule for collecting information.

3. Organizing the Information

a. Provide a format for the information which is to be collected.

b. Designate a means for coding, organizing, storing, and retrieving the information.

4. Analyzing the Information

a. Select the analytical procedures to be used.

b. Decide on a way to perform the analysis.

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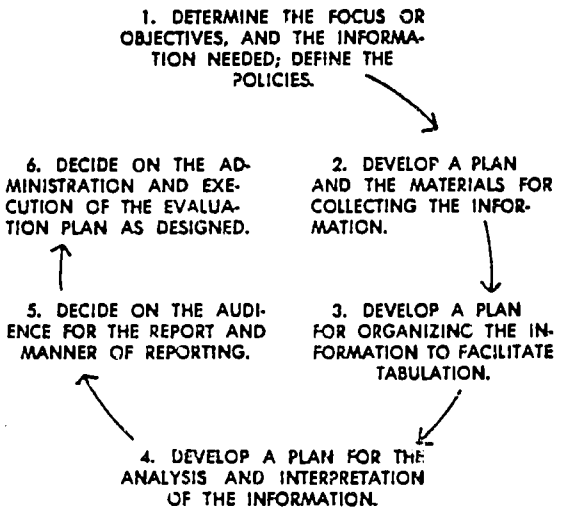

Figure 5. Evaluation design for educational programs.

5. Reporting the Information

a. Define the audiences for the evaluation reports.

b. Specify ways to provide information for the audiences.

c. Specify the format for evaluation reports and reporting sessions.

d. Schedule the reporting of information.

6. Administering the Evaluation

a. Summarize the evaluation schedule.

b. Define staff and resource requirements and plans for meeting these requirements.

c. Specify ways to meet policy requirements for conducting the evaluation.

d. Evaluate the evaluation design's potential for providing information that is valid, reliable, credible, timely, and persuasive.

e. Specify and schedule means for periodic updating of the evaluation design.

f. Provide a budget for the total evaluation program.

TWO TYPES OF EVALUATION

County Extension workers are faced with two types of evaluation. These can be seen by asking two evaluative questions: "How well did I do in my educational program with a particular group?" and "How well did the members of the group do whatever I was teaching?" The first has to do with performance by the Extension worker, the second with the performance of the participant. Both are needed for adequate evaluation of the total program; neither alone will give the evaluation needed for program improvement. There is something to the argument that "It's results that count." However, there are so many variables entering the adoption process and the final results achieved by a participant in an educational program until it is not a fair and usable evaluation to rely on results alone. Briefly, here are the requirements for the two types of evaluation.

Specific plans for each step of the *educational program* must be developed and clearly stated, including the time and method of implementation; for example, letters, meetings, follow-up, etc. In other words, a clearly stated educational program for a particular group of people over a designated period of time must be specified. Expected outcomes in terms of participation of people would be part of the specific plan. Such planning could then be readily evaluated in terms of "Did I do the things planned and how well?"

The evaluation of the participants should be built around the specific purposes for being involved in the program. Was it to get certain practices started? Or was it only for knowledge and understanding? The evaluation would be built around the evidences to look for to know whether the objectives were accomplished. In the case of agricultural programs, yields in bushels or pounds are often risky evaluation measures because of the many variables. It would be more accurate to evaluate the extent to which the approved practices were used in the production process and hope for the right amount of rain!

THE DOUBLE LOOK AND HUMAN SIDE

Two other areas need special attention in evaluating Extension programs.

These can be called the double look and the human side of evaluation.

The Double Look. Since Extension is a public agency, there needs to be a look back and a look to the future. This means little more than hindsight and foresight.

The systematic assessment of past performances in terms of effectiveness of agency programs and activities, as well as any unintended consequences, is retrospective in nature. This is important to any public agency and is an essential part of accountability. To the public, who benefits and

how is an important question in being accountable.

Many people see evaluation only as retrospective. For the Extension worker, evaluation has a second dimension—looking ahead. This evaluation is prospective in orientation. How can you evaluate a program that has not occurred? By simply moving forward the evaluation of the alternative ways of developing or implementing the program. For example, look closely at the alternatives of an on-going program. One alternative is to continue the program as now being done. But to evaluate this approach, other alternatives need to be developed and evaluated in such areas as time required, people involved, resources, etc. The CIPP Model can be used here to advantage. In short, to project alternatives and evaluate them in terms of expected results is to "move hindsight up to foresight."

An example of this prospective evaluation is the case of the article written for the local newspaper. There are basic guidelines for writing any article, such as the Fog Index which gauges readability, that can be better applied as the article is being written rather than after it has been published. There are basic principles of program planning as well as principles of learning. Recognition of these in evaluating in advance is an evaluative tool that the Extension worker should not overlook.

THE HUMAN SIDE OF EVALUATION. The Cooperative Extension Service is a people's program. As indicated earlier, results of ACES programs are seen as changes in the way things are done in the home, the community, or on the farm and in other agricultural businesses. However, from an educational viewpoint, such changes are reflecting *change in people*--in what they know, can do, and feel. The evaluation of an educational program, then, is an evaluation of the changes in people as a result of participating in an Extension program.

A related problem in evaluating changes in people is the extent to which the situation (context) is considered in evaluating the outcome. "He did well, considering his situation." This is a human consideration. Yet, how far do you modify outcomes in keeping with the situation? A basic guide is to establish a *minimum acceptable level* in terms of outcome. This should be reasonable and understood by all concerned. This is especially important in 4-H and other activities with young people who have not developed clear ideas of standards for performance in a given area. Helping people develop such standards is an important part of an educational program, and the value placed on reaching these standards is a key part of the evaluation process.

IV. Summary

The plan of work is a guide or roadmap for the Extension agent to follow in carrying out the day-to-day activities of the Extension program. Effective planning involves listening to the people affected by the program, consulting specialists in the discipline or specialty areas, and analyzing the work environment. There are specific steps and processes to follow to prepare the plan properly. The plan contains five parts, each interwoven and related to the other. The situational statement presents the specific problems and opportunities; objectives state the desired changes on the part of the specific audience. Methods state how this will be done; expected results relate to desired program results; and techniques of evaluation provide accurate ways to determine accomplishments.

Evaluation is a concept built into the total program development process. Proper evaluation furnishes facts and understanding for better decision-making. To provide information for decision-making, evaluation must be planned for. One model or guide is the CIPP procedure which directs the evaluation process before, during, and after the educational program.

Education is the business of the Cooperative Extension Service. Dynamic educational programs are more effectively implemented when properly planned and evaluated.

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The Alabama Cooperative Extension Service

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United States
Environmental Protection
Agency

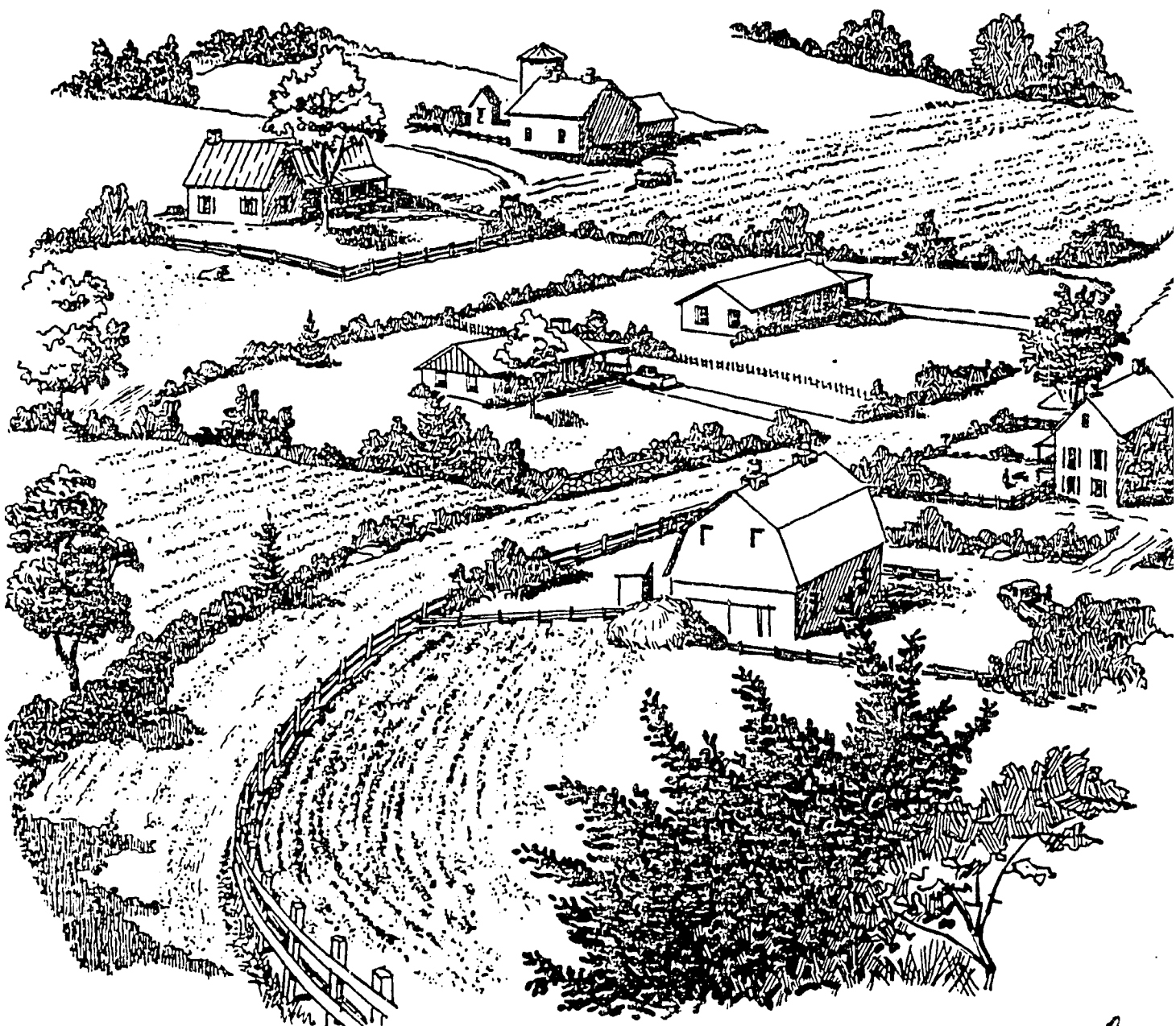
Office of Water
Program Operations
Washington DC 20460

January 1980

EPA

Small Wastewater Systems

Alternative Systems for Small Communities and Rural Areas



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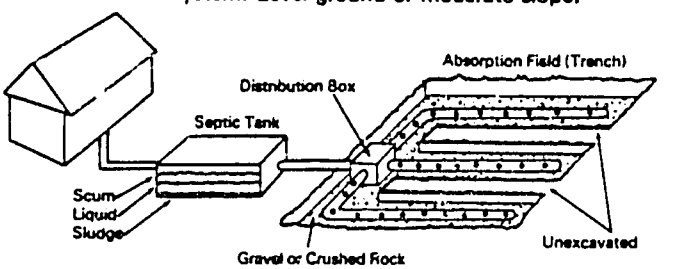
Small Wastewater Systems

Alternative Systems for Small Communities and Rural Areas

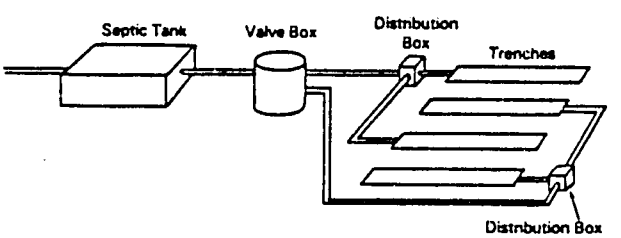
1 Septic Tank & Soil Absorption Field (Trench)

Sewage bacteria break up some solids in tank. Heavy solids sink to bottom as sludge. Grease & light particles float to top as scum. Liquid flows from tank through closed pipe and distribution box to perforated pipes in trenches; flows through surrounding crushed rocks or gravel and soil to ground water (underground water). Bacteria & oxygen in soil help purify liquid. Tank sludge & scum are pumped out periodically. Most common onsite system. Level ground or moderate slope.



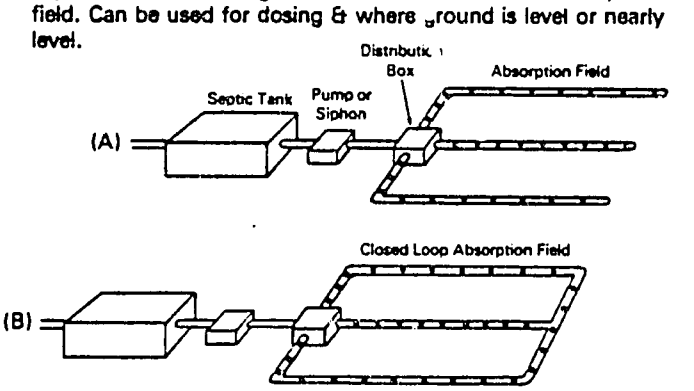
4 Septic Tank with Alternating Absorption Fields

One field rests while other is in use. Allows field to renew itself. Extends life of field. Provides standby if one field fails. Valve directs sewage liquid to proper field. Fields usually switched every 6-12 months.



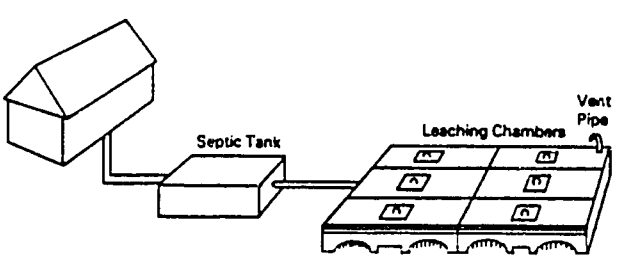
5 Septic System Refinements: (A) Dosing (B) Closed Loop

(A) Pump or siphon forces liquid to perforated pipes in controlled doses so all pipes discharge liquid almost at same time (dosing). Spreads liquid more evenly & gives field chance to dry out between dosings. (B) Variation of Sketch 1 absorption field. Can be used for dosing & where ground is level or nearly level.



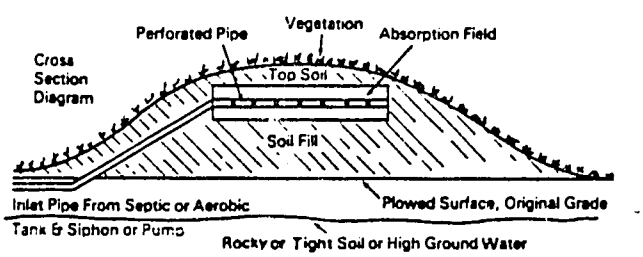
8 Septic Tank & Leaching Chambers

Open-bottom concrete chambers create underground cavern over absorption field. Liquid is piped into cavern & spread over field by troughs, splashplates, or dams. Liquid filters through soil. Chambers replace perforated pipe, trenches, & rocks of conventional absorption field. Access holes at top allow maintenance & soil inspection.



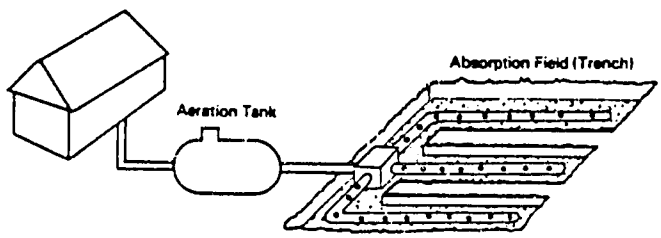
9 Mound System (Used with Septic or Aerobic Tank)

Liquid is pumped from storage tank (as in Sketch 21) to perforated plastic pipe in sand mound that covers plowed ground. Liquid flows through rocks or gravel, sand, & natural soil. Mound vegetation helps evaporate liquid. Rocky or tight soil or high water table.



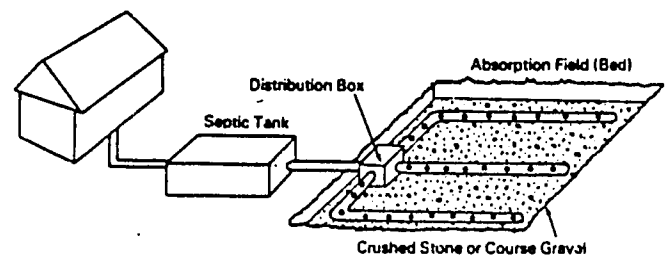
2 Aerobic System & Soil Absorption Field

Air and wastewater are mixed in tank. Oxygen-using (aerobic) bacteria grow, digest sewage, liquefy most solids. Liquid discharges to absorption field where treatment continues. Can use same treatment & disposal methods as septic tank. Maintenance essential. Uses energy.



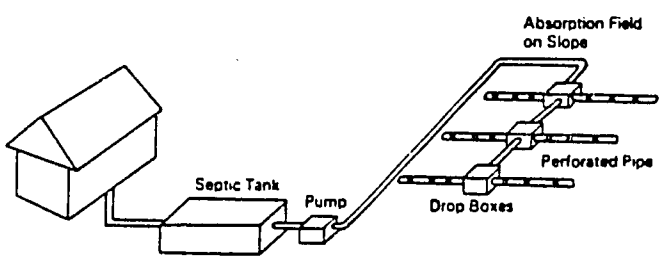
3 Septic Tank & Soil Absorption Field (Bed)

Similar to Sketch 1 but smaller field. Total field excavated. Used where space limited. Nearly level ground.



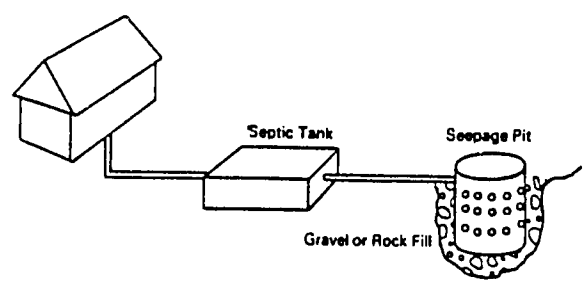
6 Septic Tank with Sloping Field—Serial Distribution

Pump forces liquid to perforated pipes in contoured absorption field. Drop boxes regulate liquid flow so highest trench fills up first, second fills up next, & lowest fills up last. Plastic fittings can be used instead of drop boxes to regulate flow. Used on slopes.



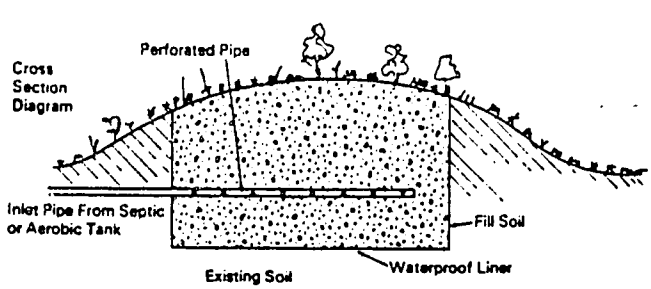
7 Septic Tank with Seepage Pit

Liquid flows to pit that has open-jointed brick or stone walls surrounded by rocks. Precast tanks with sidewall holes can also be used. Liquid seeps through walls & rocks to surrounding soil. Pit sides are cleaned periodically to prevent clogging.



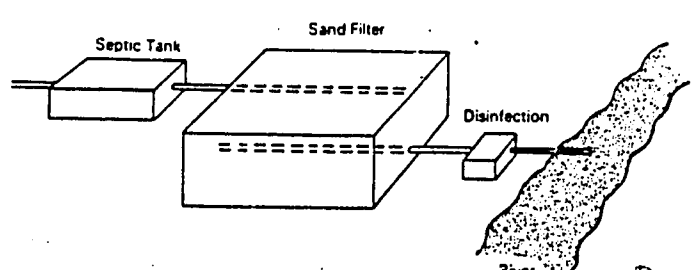
10 Evapotranspiration Bed (Used with Septic or Aerobic Tank)

Similar to Sketch 9 but sand bed is lined with plastic or other waterproof material. Bed could be mound or level. Liquid evaporates because liner prevents it from filtering through natural soil. Plants speed evaporation by drawing moisture from soil & breathing it into the air. Used where conventional absorption field not possible.



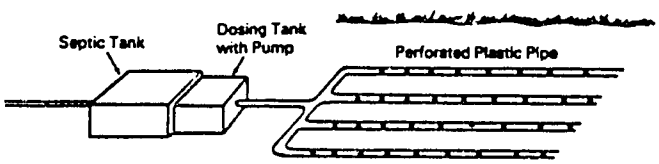
11 Septic Tank, Sand Filter, Disinfection & Discharge

Filter is ground-level or buried sand pit. Liquid enters perforated pipe at top & filters through sand & gravel to bottom pipe. Bottom pipe conducts liquid to disinfection tank. Liquid discharges to stream or ditch. Variations are intermittent sand filter & recirculating sand filter. Used where soil absorption field not possible.



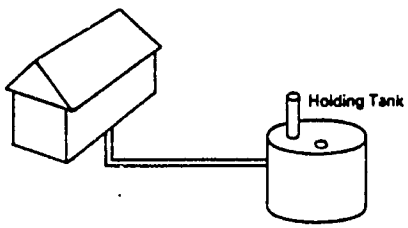
12 Low-Pressure Subsurface Pipe Distribution

Network of small-diameter perforated plastic pipes are buried 6"- 18" in 4"- 6"-wide trenches. Pump forces liquid through pipes in controlled doses so liquid discharges evenly. Site & soil determine pipe layout & pipe-hole size & number. Absorption field is same size as conventional field. Rocky or tight soil or high water table.



13 Holding Tank

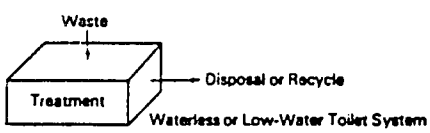
Sewage flows to large, underground, watertight storage tank. Tank is pumped periodically & sewage hauled away. Isolated or remote areas where absorption field not possible. Sewage hauling cost high.



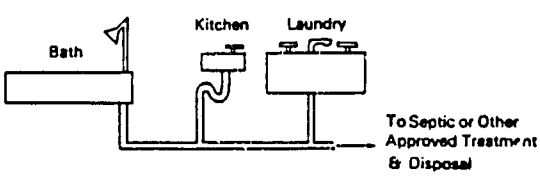
16 Dual Systems: Blackwater & Graywater

Many systems. In this one: (A) toilet wastes (blackwater) are handled by waterless or low-water toilet system [Sketch 15]. (B) Other household wastewater from kitchen, bath, laundry (graywater) needs separate treatment & disposal.

(A) Blackwater (Toilet Wastes)

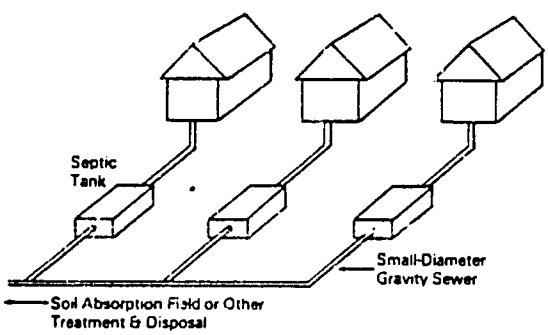


(B) Graywater (Other Household Wastewater)



17 Small-Diameter Gravity Sewers (Collection System)

4"- 6" pipe is sloped so liquid from septic or aerobic tank flows through pipe to treatment & disposal. Treatment & disposal system can be conventional or alternative. Small pipe costs less than conventional 8" pipe.



19 Land Application

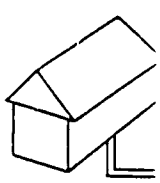
Sewage liquid is applied to land to nourish vegetation & purify liquid. Methods:

1. **Irrigation**—Liquid is applied to crops or to forests (silviculture) by sprinkling, flooding, or ridge & furrow. Liquid is sometimes disinfected before application.
2. **Overland flow**—Liquid flows through vegetation on graded slope. Runoff is collected at bottom & reused or discharged to river or stream. Suitable for tight soils.
3. **Rapid infiltration**—Partly treated sewage is applied in controlled doses to sandy soil. Solids break down. Liquid purifies as it seeps to ground water (underground water) or is collected & may be reused.

Aquaculture:

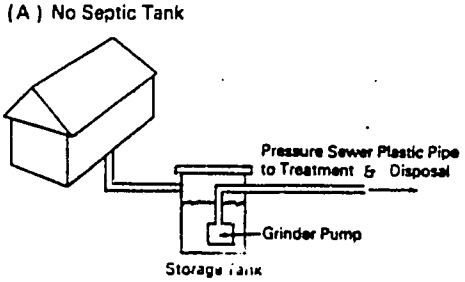
Plants & animals that grow in wastewater help purify water by digesting pollutants. Harvest is used as food, fertilizer, etc.

20 Pressure Sewers, GP (Grinder Pump)

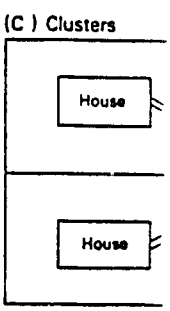


Unit grinds sewage & pumps it through small-diameter plastic pipe to central or alternative treatment & disposal. Doesn't use septic tank but existing tank (B) may remain for emergency storage. Used for one or several homes (C).

(A) No Septic Tank

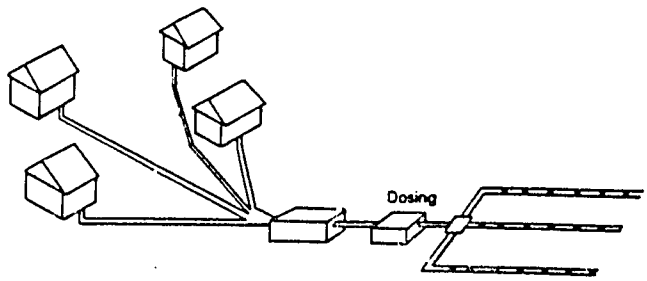


(C) Clusters



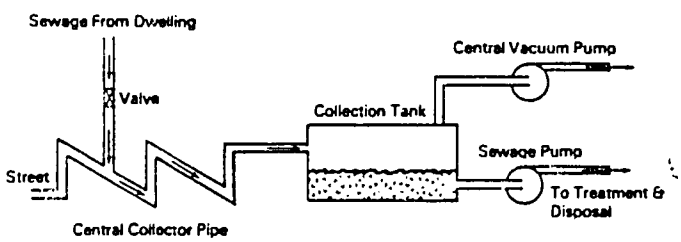
14 Cluster System
(Two or More Users on One Alternative System)

Several houses are served by common treatment & disposal system. Houses could also have onsite septic or aerobic tanks with liquid conducted to common absorption field. Clusters of houses can also use other alternative systems, such as mounds (Sketch 9), pressure & vacuum sewers (Sketches 18, 20, 21), & sewage treatment lagoons.



18 Vacuum Sewers
(Collection System)

Vacuum pump creates vacuum in collector pipes. Valve opens when sewage from dwelling presses against it. Sewage & plug of air behind it enter pipe. Air forces sewage to collection tank. Sewage pump forces sewage from tank to treatment system. Needs standby electric power & failure alarm system. Can be used with large cluster systems (Sketch 14).



15 Waterless or Low-Water Toilet Systems*

Composting: No water.
Large & small systems. Converts toilet wastes & most food wastes to compost. Electric vent fan & heating element optional on large systems; essential on small systems. Proper care vital.

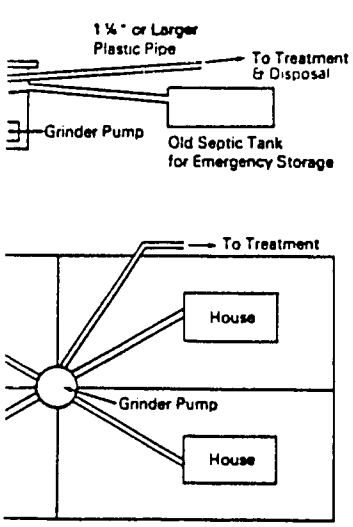
Incinerating: No water.
Electricity, gas, or oil burns solids & evaporates liquid. Small amount of ash is removed weekly. Roof vent. Proper care essential.

Recycling Oil Flush: No water.
Similar to water-flush toilet but uses oil for flush. Oil & wastes go to large storage tank where wastes settle at bottom & oil rises to top. Filtered oil recycles for flush. Storage tank is pumped & oil replaced periodically. Uses electricity. Proper care essential.

Recycling Chemical: Low water.
Water-chemical flush mixture is pumped into toilet bowl. Mixture & wastes go to storage tank. Filtered liquid recirculates for flush. Permanent or portable types. Permanent needs water hookup. Storage tank is pumped & chemicals added periodically. Uses electricity. Proper care essential.

Recycling Water: Low water.
Various systems. Some reduce wastes to water, gas, & vapor. Treated wastewater recycles to flush toilet. System vents to outside. Multiflush commercial units available. Most systems use electricity. Professional maintenance essential.

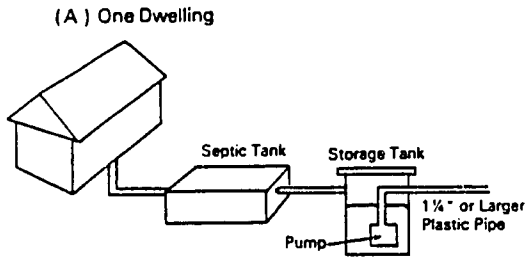
**Treat toilet wastes (blackwater). Other household wastewater (graywater) needs separate treatment & disposal system.*

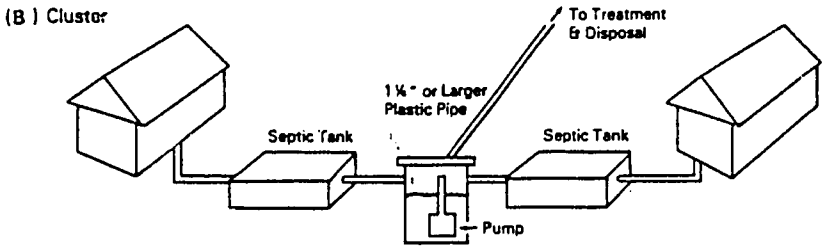


21 Pressure Sewers, STEP
(Septic Tank Effluent Pump)

(A) One dwelling. Pump forces liquid from septic tank through plastic pipe to further treatment & disposal. Sludge is pumped from septic tank periodically.

(B) Cluster system. Liquid from several septic tanks flows to one pumping tank. Pump forces liquid through plastic pipe to treatment & disposal.





GPO 864-289

Why Small Systems?

Lower Water & Sewer Rates	Save Energy, Water, Materials	Save Prime Farmland, Prevent Urban Sprawl
Rates skyrocket when a few people have to pay for a large system.	Most small systems use less.	Large central sewage systems in rural areas can bring unwanted development.

Federal Government Pays 85%

EPA Construction Grants Program

If you're a *small community* or a *sparsely populated area of a large community* and have a water pollution problem caused by buildings in use December 27, 1977:

- The Government pays 85% of eligible costs for alternative systems if your State, local government, and EPA approve them for your project. Your community, often with State help, pays the other 15%. Farmers Home Administration, Economic Development Administration, Housing & Urban Development, and Community Services Administration programs also help in some areas.

- The Government pays to repair or replace the system if it fails within 2 years of final inspection because it proves unsuited to the project or its design concept is faulty.

- Systems can be *publicly or privately owned.* They can be for residences or small commercial establishments.

— *Publicly owned* systems are owned by the local government.

— *Privately owned* systems are owned by the property owner or a community organization. They can be funded if:

- An authorized local government unit applies for the grant; guarantees a system for inspection, proper operation, maintenance, and user charges; and says public ownership isn't practical;
- They're more cost effective than a conventional central system;
- The residence is a principal dwelling; vacation or second homes are not eligible.
- Commercial users pay back their share of system cost.

You Must Consider Alternatives

EPA can't approve a central system plan submitted after Sept. 30, 1978, unless the community shows it considered alternative systems.

More Information From:

- **EPA National Small Wastewater Flows Clearinghouse**
  West Virginia University; Morgantown, WV 26506; 800-624-8301.

- **Center for Environmental Research Information**
  26 W. St. Clair; Cincinnati, OH 45268; 513-684-7391.

- **Your EPA Regional Office**

  1. Boston
  (Conn., Maine, Mass., N.H., R.I., Vt.); JFK Federal Bldg.; Boston, MA 02203; 617-223-7210.

  2. New York
  (N.J., N.Y., P.R., V.I.); 26 Federal Plaza; New York, NY 10007; 212-264-2525.

  3. Philadelphia
  (Del., Md., Pa., Va., W.Va., D.C.); 6th & Walnut Sts.; Philadelphia, PA 19108; 215-597-9814.

  4. Atlanta
  (Ala., Ga., Fla., Miss., N.C., S.C., Tenn., Ky); 345 Courtland St., N E.; Atlanta, GA 30308; 404-881-4727.

  5. Chicago
  (Ill., Ind., Ohio, Mich., Minn., Wis.); 230 S. Dearborn St.; Chicago, IL 60604; 312-353-2000.

  6. Dallas
  (Ark., La., Okla., Tex., N.Mex.); 1201 Elm St.; Dallas, TX 75270; 214-767-2600.

  7. Kansas City
  (Iowa, Kans., Mo., Nebr.); 324 E. 11th St.; Kansas City, MO 64108; 816-374-5493.

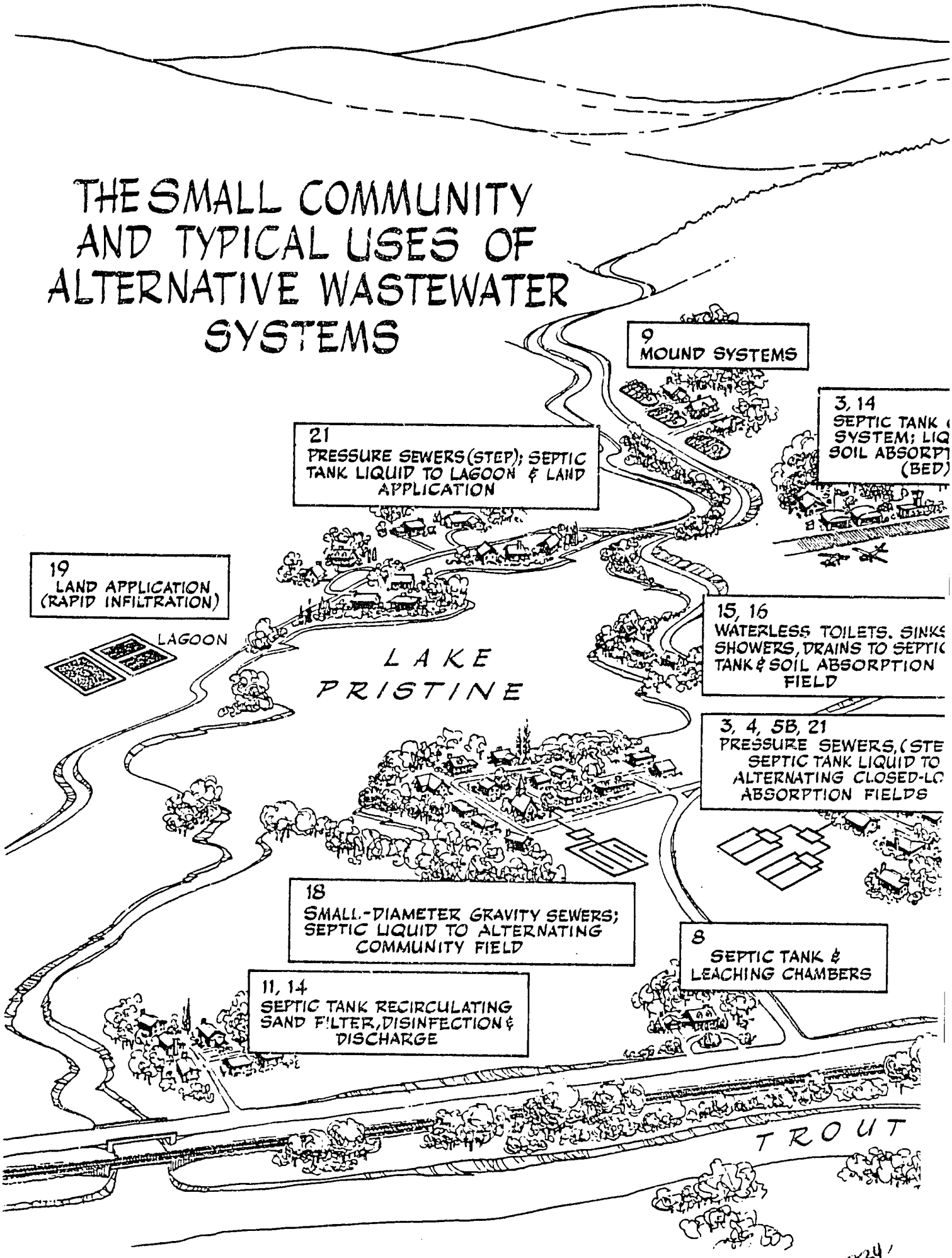
  8. Denver
  (Colo., Utah, Wyo., Mont., N.D., S.D.); 1860 Lincoln St.; Denver, CO 80203; 303-837-3895.

  9. San Francisco
  (Ariz., Calif., Guam, Hawaii, Nev., Amer. Samoa, Trust Territories of the Pacific); 215 Fremont St.; San Francisco, CA 94105; 415-556-2320.

  10. Seattle
  (Alaska, Idaho, Oreg., Wash.); 1200—6th Ave.; Seattle, WA 98101; 206-442-1220.

Engineers and consultants: For detailed technical information get EPA's onsite systems manual free from Center for Environmental Research Information; 26 W. St. Clair; Cincinnati, OH 45268; 513-684-7391 ; and Innovative and Alternative Technology Assessment Manual from Municipal Construction Division (WH-547), OWPO, EPA, 401 M St. SW, DC 20460; 202-426-8976 .

This publication isn't meant to be a comprehensive guide to alternative systems. It tries to acquaint the layperson with some representative systems used in the United States. EPA does not endorse, approve, or disapprove any system described here. Not all systems shown are approved by all jurisdictions. To get EPA funds, a project must meet Federal, State, and local standards.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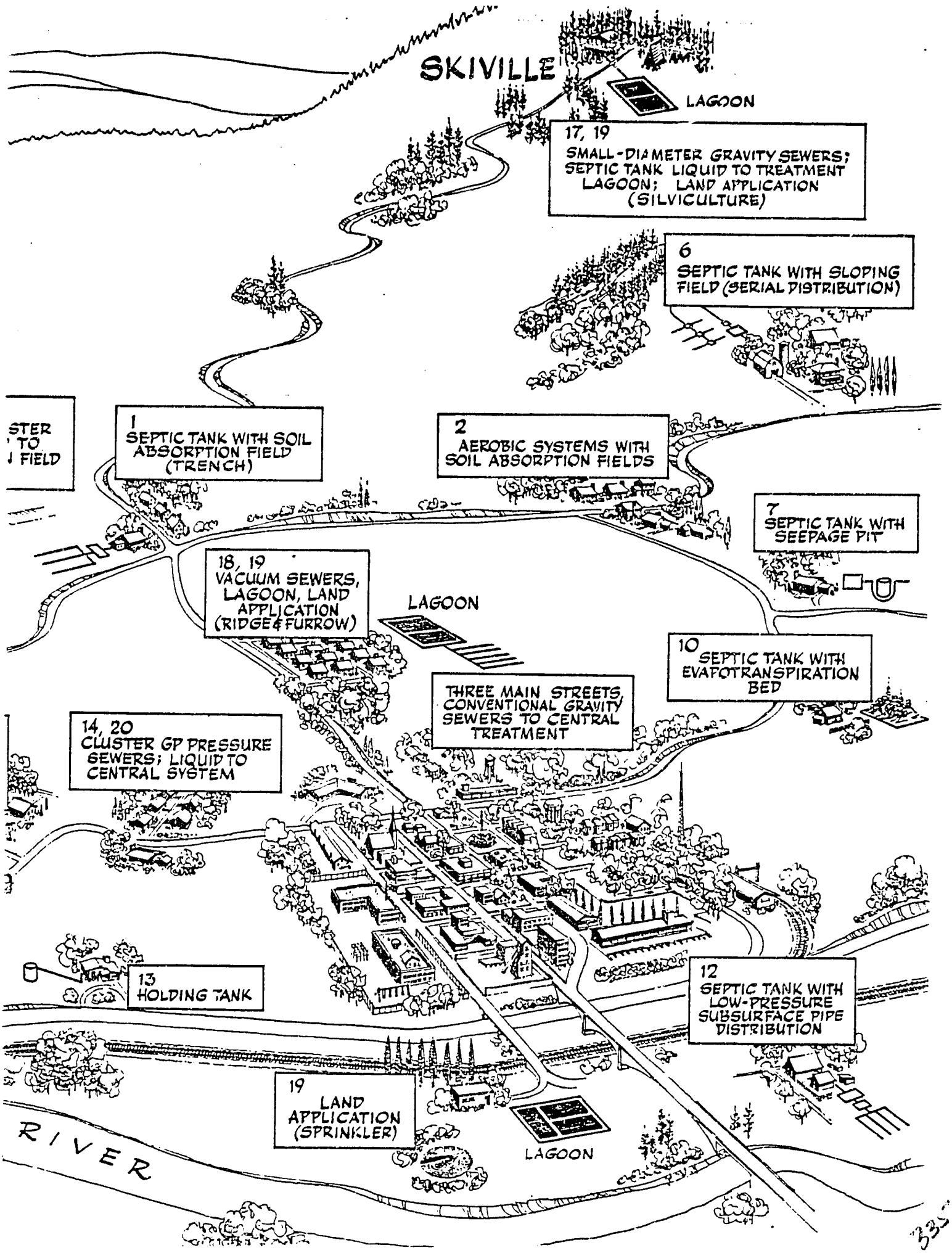
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ENVIRONMENTAL CONSIDERATION
IN LAND USE PLANNING

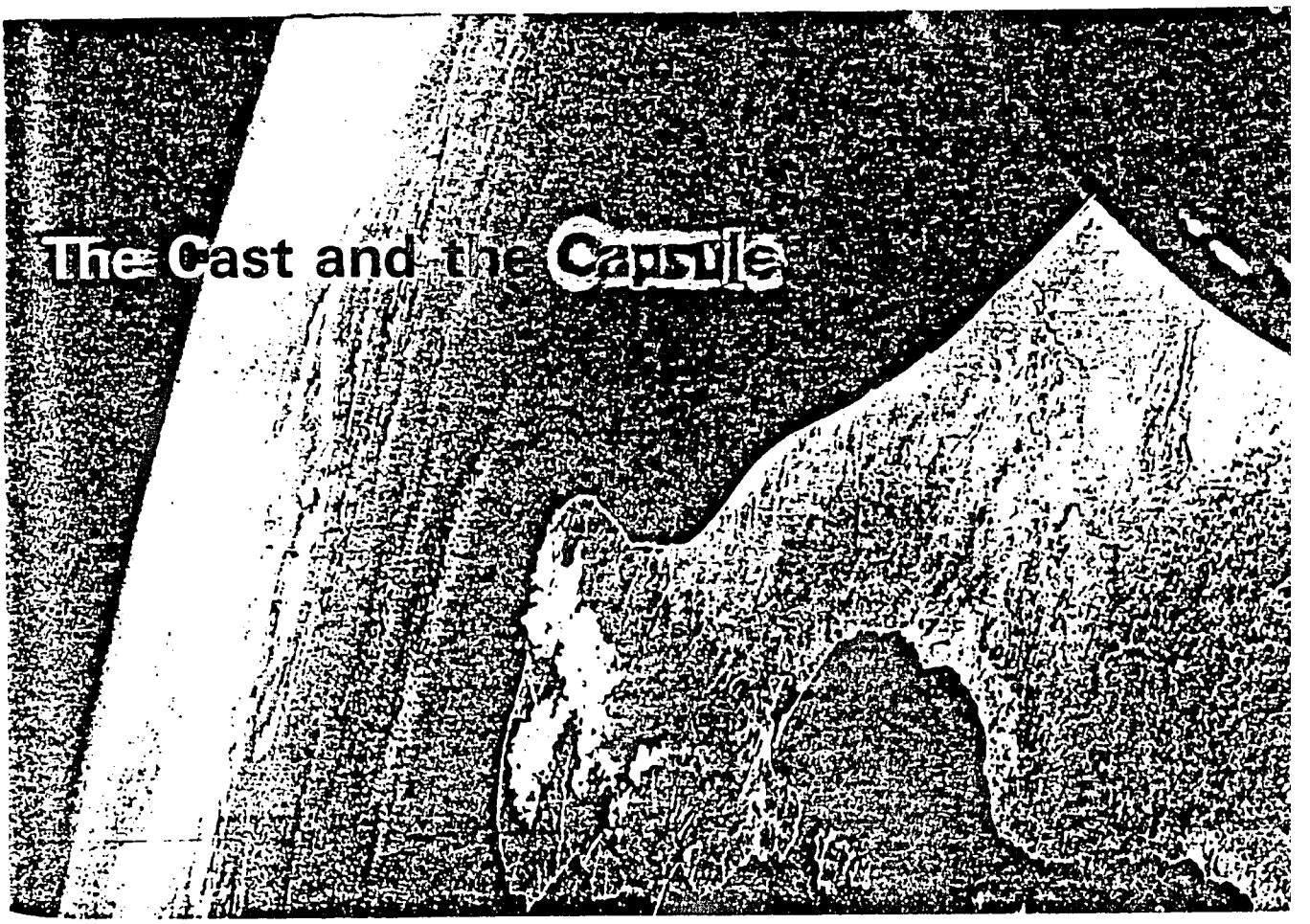
1. "The Cast and the Capsule"

2. "Environmental Management in Africa"

3. "National Wildlife's Tenth Annual Environmental Quality Index: 1969-1979 - A Decade of Revolution"

4. "Excerpts from "Environmental Reviews at the Commumity Level - A Program Guide"

Source: Design With Nature,
Ian L. McHarg, 1971
Doubleday and Company, Inc.,
Garden City, New York



The Cast and the Capsule

Each year I confront a new generation of graduate students, secure in their excellence, incipient or confirmed professionals in one or another of the planning or design fields. My most important objectives in this first encounter are to challenge professional myopia, exclusively man-centered views, to initiate consideration of basic values and to focus particularly on the place of nature in man's world—the place of man in nature.

Over the years I have used two stories mercilessly in order to review accepted values.

The first is paraphrased from an image conceived by Loren Eiseley:*

Man in space is enabled to look upon the distant earth, a celestial orb, a revolving sphere. He sees it to be green, from the verdure on the land, algae greening the oceans, a green celestial fruit. Looking closely at the earth, he perceives blotches, black, brown, gray and from these extend dynamic tentacles upon the green epidermis. These blemishes he recognizes as the cities and works of man and asks, "Is man but a planetary disease?"

The silence that follows provides the appropriate setting for the next story—my own, bred from introspection on the increase of nuclear power.

The atomic cataclysm has occurred. The earth is silent, covered by a gray pall. All life has been extinguished save in one deep leaden slit, where, long inured to radiation, persists a small colony of algae. They perceive that all life save theirs has been extinguished and that the entire task of evolution must begin again—some billions of years of life and death, mutation and adaptation, cooperation and competition, all to recover yesterday. They come to an immediate, spontaneous and unanimous conclusion: "Next time, no brains."

The audience, in common with western society at large, believes that the world, if

*Lecture by Loren Eiseley in the series, *"The House We Live In,"* WCAU-TV, Feb. 5, 1961.

not the universe, consists of a dialogue between men, or between men and an anthropomorphic God: the result of this view is that man, exclusively, is thought divine-given dominion over all life, enjoined among all creatures to subdue the earth. Nature is then an irrelevant backdrop to the human play called Progress, or Profit. If nature is brought to the foreground, it is only to be conquered—man versus nature.

In this context it is salutary to suggest that the path and direction of evolution may not be identical to human ideas of destiny; that man, while the current, latest dominant species, may not be an enduring climax; that brain may or may not be the culmination of biological evolution or it might in contrast be an aberration, a spinal tumor, and finally, although no man will hear it, the algae may laugh last. The burden of proof, then, lies with man and brain. He is required to demonstrate that he is capable of understanding and managing the world of life to ensure survival.

We can conclude that there are two extreme viewpoints of man-nature. In the first, anthropocentric man—ignorant of evolutionary history, innocent of man's dependence, his allies and cohorts, low-browed and brutish—destroys as he goes, while adulating man and his works. (Can we suggest that his aggression is only a cultural inferiority complex?) The opposing view is less certain of man's place. It reserves the right to justify man as not only a unique species, but one with the unequaled gift of consciousness. This man, aware of his past, his unity with all things and all life, proceeds with a deference born of understanding, seeking his creative role.

If we can abandon the sad arrogance of ignorance and introduce a mood of reasonable inquiry, then circumspection will temper our indictment and we can reinterpret the stories. If we assume that man is a beneficent and constructive agent in the world, we could imagine the green celestial fruit as a great epidermis indeed, but we could consider the green film as cytoplasm and the black, brown, gray centers not as blemishes but as nuclei and plastids—directing, producing, storing and circulating material for the cytoplasm: the creative centers in the world life. But if we do offer this kinder interpretation, we must ask whether these centers do indeed perform the roles of nuclei and plastids for the biosphere. I think that in general the answer would have to be that they do not.

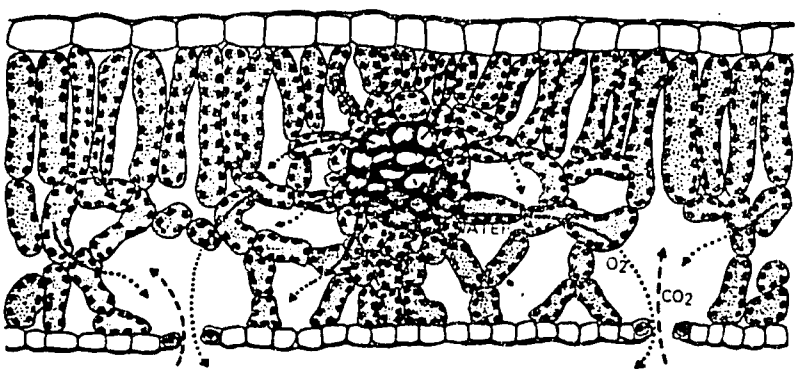
But the mood has at least changed; the cry is no longer the raucous crow of the cock on the dunghill. The question is asked, if man is not the apex of the universe and its total justification, then who are the principal actors? With whom does he share the stage?

Some years ago I spent a most instructive winter with the great architect Louis I. Kahn, searching for the appropriate elysian site for a prospective temple of science, the research arm of a large corporation. I learned much from my travels with this most perceptive of architects, but my knowledge was even more enlarged by an encounter with a member of the research organization. He was designing an experimental environment: his task was to find out how an astronaut might be sent to the moon with the least possible baggage to sustain him. This, of course, required a recirculating, which is to say, a biological system. The experiment design required a plywood capsule with a fluorescent tube representing the sun, a quantity of air, some water, some algae growing in water, some bacteria and a man. This is, you will agree, a modest hoard of groceries for so long a trip. In the hypothetical capsule the man breathes air, consumes oxygen and exhales carbon dioxide; the algae consume carbon dioxide and expel oxygen into the air which the man breathes, and so an oxygen-carbon dioxide cycle is ensured. The man thirsts, drinks some water, urinates, this passes into the water medium in which the algae and bacteria exist, the water is consumed by the algae, transpired, condensed,

ALGAE*

*Drawings by Harold J. Walter, *Algae in Water Supplies* by C. Mervin Palmer, Public Health Service Publication No. 657, U.S. Department of Health, Education and Welfare Washington, D.C. 1962 Plates 1 & 2

CHLOROPLAST*



LEAF SECTION**

**After Sinott and Wilson, *Nature: Earth-Plants-Animals*, Doubleday & Company Inc., New York, 1960, p. 72.

*Photo micrograph, NAVICULA PELLICULOSA (Breb.) Hilse, 26,000:1, *Electron Microscopy of Diatom Cells* by R.W. Drum, H.S. Penkratz and E.F. Stoermer, J. Cramer, Lehre, 1966, plate 503.

the man drinks the condensations and a closed cycle of water exists. When hungry, the man eats some algae, digests them, then defecates. Subsequently, the decomposers reduce the excrement into forms utilizable by the algae, which grow. The man eats more algae, and so a food chain has been created. The only import to the system is the light from the fluorescent tube—fossil sunlight; the only export from the system is heat.

Alas, experiments of this kind have not been sustained for more than twenty-four hours, a sad commentary on our understanding of man-nature. Nonetheless, they do contain splendid instructional material for the observer. The system depends first upon the sun, the net production of photosynthesis after respiration, upon the water and upon the cycling and recycling of the materials in the system by the decomposers. It is quite clear that the process requires that the substance or wastes, the output of one creature, are the imports or inputs to the others. The oxygen wastes of the plant were input to the man, the carbon dioxide of the man input to the plant; the substance of the plant input to the man, the wastes of the man input to the plant; the wastes of man and plant input to the decomposers, the wastes of these the input to the plant: and the water went round and round and round.

Is this indeed the way the world works? Yes, at least in essential terms. United we are as men, plant parasites, happily consuming the oxygen wastes of plant metabolism, rescued from encompassing ordure by both the decomposer and the plant, eating, burning and thus sustaining life from the energy of the sun, transmuted by photosynthesis. Now before we indulge in fulsome self-praise for our services to both plant and bacteria, let us stop to consider that they both existed before man and need him not at all. Our wastes are useful, but not necessary.

When I first pondered upon s experiment I found that I had to reform[illegible] my view of

man-nature. Instead of a paradise with Adam and Eve placed large in a garden graced by some benign, beautiful and useful plants and animals, the experiment showed that these myriad, beautiful creatures, thought to be a measure of grace added to life, were indeed indispensable, the source of life. Had the astronaut traveled to the moon with his companions, there is some doubt as to whether he would have found the algae and decomposers beautiful, but he would clearly have concluded that they were indispensable.

Moreover, whatever view our moon traveler had of man and environment as separate entities before his departure, it would surely have crossed his consciousness that, given enough time, the probability existed that all that had once been algae might well be man, all that had once been man, algae. The only difference between them, in terms of matter, lay in the templates of the genetic codes. What then is the environment? What then is man?

As I never obtained a college degree and entered graduate school without this dispensation, I never acquired the illusion of being educated which these diplomas often confer. Teaching is that device whereby I assemble a fragmentary, ragged and belated education. As it incurs no cost to the student and cannot be terminated with a degree, it clearly has certain advantages. But it does also have embarrassments, not least of which is the consternation of confronting the commonplace of knowledge as total novelty late in life. I well remember that occasion, when I first heard that all life, with minor exceptions, is now, and forever has been, entirely dependent upon photosynthesis and the plant. I recall looking around me, searching for other eyes equally overwhelmed by this revelatory statement. I found only the dead faces of those who had long since absorbed this information and for whom it had no moving power.

And that was not all. Not only is the chloroplast the overwhelmingly dominant mechanism whereby the light of the sun is transmuted into the substances supporting all life, the sugar and carbohydrates, but there are grounds for believing that it is from the exhalations of all plants in all time that an atmosphere with free oxygen has developed. Indeed, all food, all fossil fuels, fibres, all atmospheric oxygen, the stabilization of the earth's surface and its terrestrial water systems, the melioration of climate and microclimate have been accomplished by the plant: all animals and thus all men were plant parasites. It is the plant that colonized the land and thus permitted the evolution from the sea of amphibians, reptiles, mammals and man, and this dependence persists unchanged. Nor is this basic reliance negated by the fact that many animals perform essential services for plants.

This realization of dependence was a crushing blow to anthropocentrism. I looked around to see what effect this had had upon the class. Were they aware that, at least in thermodynamic terms, the world consisted of a working partnership between the sun and the leaf as man looked on—irrelevant, smiling benignly upon the scene, secure in the illusion of his primacy?

Suddenly I had an image of a green world, half turned towards the sun, leaves cupped to its light, encapsulating it through their templates, into their beings, this modified and ordered sunlight then transmuted by the inordinate variety of creatures and, through plants and animals, to man. Thus all life now, the residues of all life past, the transformations of all life in all time, all creatures and all men, are based upon the chloroplast, turned to the sun, arresting and ordering its energy as it passes to disorder. It is, as it were, as if the leaf said to the sun: "May I use some of your energy before it is degraded?" And the sun assented. So the leaf took the energy, ordered it into its being, sustained its growth and evolution, and those of all other creatures, before the energy, degraded, was yielded to disorder.

Consternation is an appropriate term to describe my continuing encounters with old but astonishing information. The second of these came, not from a lecture but from a book, *The Fitness of the Environment* by Lawrence Henderson. The most startling statement opens the preface:

> *Darwinian fitness is compounded of a mutual relationship between the organism and the environment. Of this, fitness of environment is quite as essential a component as the fitness which arises in the process of organic evolution; and in fundamental characteristics the actual environment is the fittest possible abode of life.*

This conception then precedes the Darwinian theory in that it postulates evolution of matter to create the fitness of life and its evolution. It supplements natural selection, for not only is the successful organism adapted to the environment, but the environment is fit for the organism. "Fit" involves the assumption of the environment's provisions of opportunity for the organism, the latter is a response to this opportunity. Henderson supports his proposition by elaborating upon the characteristics of carbon, hydrogen and oxygen—to which George Wald would add nitrogen, including then those elements which constitute 99% of all organisms. But, of all matter which exhibits fitness, Henderson chooses the oceans and water:

> *The fitness of the environment results from characteristics which constitute a series of maxima—unique or nearly unique properties of water, carbonic acid, the compounds of carbon, hydrogen and oxygen and the ocean—so numerous, so varied, so nearly complete among all things which are concerned in the problem, that together they form certainly the greatest possible fitness. No other environment consisting of primary constituents, made up of other known elements, or lacking water and carbonic acid, could possess a like number of fit character-*

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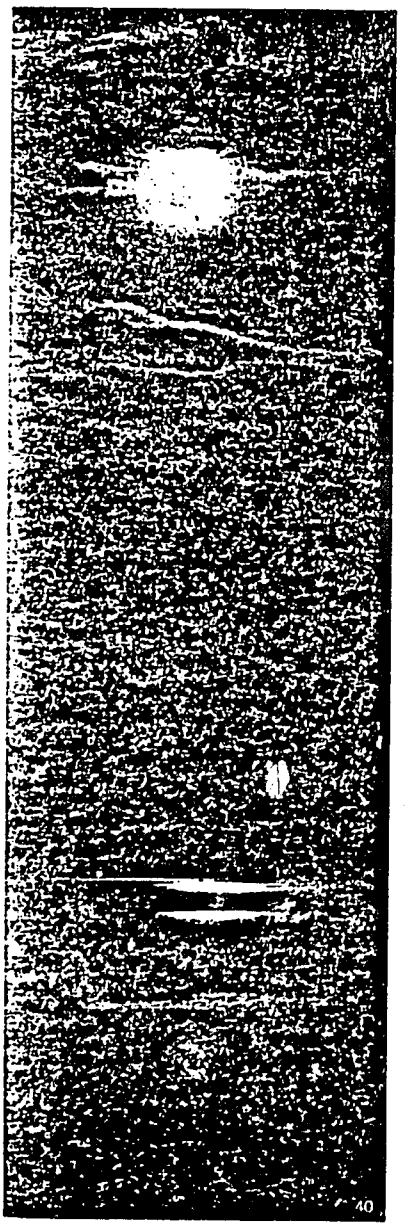


istics, or in any manner such great fitness to promote complexity, durability, and the active metabolism in the organic mechanism we call life. *

The oceans, three-quarters of the earth's surface, are a great stable body with little variation in temperature and alkalinity and with both richness and constancy of chemical composition. It was here in this realm where sunlight penetrates, but beyond the range of toxic ultraviolet rays, that life could and did emerge. Here in this ancestral home life was created. The body fluids of simple marine organisms are all but identical with seawater. The blood of man is similar to the seas of earlier times. Loren Eiseley has said that the dimension of man's emancipation from the sea is the length of that cell which separates him from its source of blood, the ancient brine. All creatures are essentially aqueous solutions confined in membranes.

Ecologists describe the thin film of life covering the earth as the *biosphere*, the sum of all organisms and communities, acting as a single superorganism. Persuasive evidence for this derives from the oceans themselves—Henderson observed a marked correspondence between the regulatory mechanisms of the ocean and organisms, accomplished by temperature regulation through evaporation and regulation of alkalinity.

It is at least worthy of mention that the regulation of the ocean in general bears a striking resemblance to a physiological regulatory process, although such physiological processes are supposed to be the result of organic evolution alone. **

While the pyramid of life is dependent upon the sunlight captured by the chloroplast, the great work performed by the sun—a gigantic multiple of that employed in photosynthesis—is the evaporative phase of the hydrologic cycle in which water is transmuted into vapor, elevated and then precipitated as rain or snow, sustaining those terrestrial creatures who have escaped from the sea but who are still dependant upon it.

Think then of the great work of the sun, distilling, raising and dropping the rain upon the waiting creatures on the land, who stand like dams across the water's implacable path, encapsulating it to form the larger part of their beings, ordering it with their unique templates—reservoirs of sea rain temporarily arrested on its inexorable gravitational path to the sea, but forever raised again and again to sustain and replenish those erstwhile sea creatures, membranes enclosing a briny solution.

The man who aspires to translate is limited not only by his knowledge of language but of substance. In wishing to bring a modicum of natural science to the planning process, I am, like most other planners, seriously hampered by ignorance of the subject. Yet, truly, who would expect to find that major world processes depend upon inconspicuous creatures called Foraminifera or Azotobacter. But indeed they do.

Four elements, abundant in the world—carbon, hydrogen, oxygen and nitrogen—constitute all but one per cent of living creatures. Their characteristics as well as their abundance constitute the best evidence of the fitness of the environment. These elements are indeed abundant: carbon as CO_2 in the atmosphere, in rocks, in the oceans and, above all, in the living; hydrogen and oxygen in the hydrosphere, oxygen 20% and nitrogen 78%, by volume, of the atmosphere.

Why should these four elements play such a central role in life? In his introduction to a new edition of Henderson's book, the biochemist George Wald answers this question—"I should say, because they are the smallest elements in the periodic system that achieve stable electronic configurations by gaining respectively 1, 2, 3 and 4 electrons. The special point of gaining electrons is that this is the mechanism by which chemical

*Lawrence J. Henderson, *The Fitness of the Environment*, The Macmillan Company, New York, 1913, page 272.

***The Fitness of the Environment*, p. 188.

bonds, hence molecules, are formed. . . The point of these being the *smallest* such elements is that they tend to form the tightest and most stable bonds, and with few exceptions they alone form multiple . . . bonds. Why is that last thing important? Because, for example, in carbon dioxide the elements carbon and oxygen, by forming double bonds with one another, O=C=O, satisfy all their tendencies for chemical combination. As a result, independent molecules of carbon dioxide go off in the air as gas and dissolve in water; and from them plants can derive their substance, and animals by eating plants can derive theirs."*

Carbon, dominant in the chemistry of creatures, entered the primeval world in methane, but was oxidized to CO_2 and water. According to Hutchinson, "The resulting CO_2 could not accumulate on a wet planet . . . and so formed vast beds of limestone. The hypothetical pre-Cambrian limestone is to be regarded as the source of all CO_2 that has subsequently entered the atmosphere."**

In the modern earth carbon dioxide and thus carbon is found in the oceans, atmosphere and the rocky mantle and fixed in the biosphere. Carbon dioxide is involved in a great cycle, relatively imperfect. It begins with volcanic action releasing original and secondary sources of CO_2 that tend to concentrate in the oceanic depths. This material must be returned to the system by repeated volcanism if the cycle is to be completed. But it appears that more CO_2 is being fixed by the pelagic foraminifera in deep oceanic basins than is being returned to the system by volcanism—with a resulting net deficit. CO_2 is involved in smaller cycles—normally at the interfaces between the oceans, plants, soil and the atmosphere.

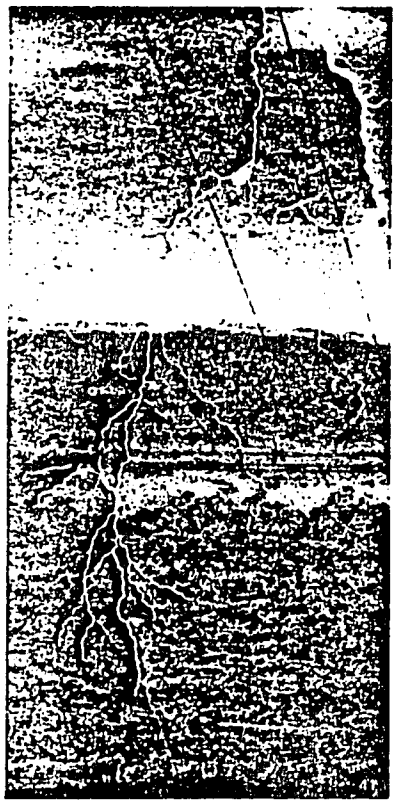
The oceans act as a major regulator in the system. CO_2 is fixed through plant photosynthesis; this is taken from the oceans, but equilibrium has been maintained with the atmosphere during geologic time. In turn, respiration of plants and animals and decomposition add CO_2 to the ocean, which tends to come into equilibrium with the atmosphere.

Carbon is the fire at the heart of life. It has the unequaled ability to form complex compounds, exceeding in number all other chemical compounds, which it derives from its ability to form chains and rings of atoms.

It is this carbon—central to life, emerging from methane, fixed in beds of ancient limestone, released by volcanism and by solution as CO_2—which is used by plants again and again but is increasingly fixed in the oceanic foraminifera and lost to the system unless returned by volcanism. There is, however, a new element in the system—the enormous production of CO_2 as a byproduct of combustion—which has vastly increased the level of CO_2 with the result that ocean and atmosphere are not now in equilibrium.

It is the union of carbon and hydrogen that produces the hydrocarbons. Hydrogen, the first element, the primeval atom, is the basis of physical and thus biological evolution. It is as important as a constituent of water as it is a partner in the hydrocarbons. It is the hydrogen bond in the water molecule which provides the essential qualities of the latter, "its great surface tension, cohesiveness, high boiling point, high heat of vaporization."*** And those are the attributes that Henderson used to identify water as the most fitting of the attributes of the environment.

Oxygen exists as 20% of the atmosphere. In the form of oxides it permeates the oceans, the lithosphere and life. It is the input in animal and plant respiration and decomposition, it is a net product of photosynthesis over time. It is the union of oxygen and hydrogen which constitutes water and gives it the essential attributes it exhibits; it is the union of oxygen and carbon which constitutes that most essential compound, carbon



dioxide. We need oxygen for survival.

While 78% of the atmosphere consists of nitrogen, it is in rocks that it is most abundant, constituting five-thousandths by weight. A considerable quantity of nitrogen is fixed from the atmosphere by organisms. According to Eugene Odum this may be as much as two hundred pounds per acre in cultivated areas, from one to six pounds per acre in the biosphere as a whole. Unlike the cycle of carbon dioxide and, as we shall see, phosphorus, the nitrogen cycle is relatively perfect. The major source of free nitrogen is the atmosphere. This is made available to

*George Wald in *The Fitness of the Environment* by Lawrence J. Henderson, Beacon Press, Boston, 1958, p. xx.

**G.E. Hutchinson, The Biochemistry of the Terrestrial Atmosphere, in *The Earth as a Planet*, edited by G.P. Kuiper, University of Chicago Press, Chicago, 1954, p. 388.

***[illegible] 1958, p. xxii.

plants by photochemical fixation, by nitrogen-fixing bacteria and algae, and, it is speculated, by lightning. As nitrates it is used in the protein synthesis of plants, animals and bacteria. The wastes of protein synthesis are reduced by decomposers to amino acids and organic residues. These are transformed by bacteria into ammonia, then to nitrites and finally to nitrates available once more for plant synthesis.

Nitrogen is added to the cycle from igneous rocks and is a product of volcanic action. There are losses to oceanic sediments, some of which are retrieved from marine birds and fishes.

In the cycles of oxygen, hydrogen and carbon, living organisms play an important part, but it is nonspecific—that is, all photosynthetic plants perform the same role in the oxygen-carbon dioxide cycle. But in the nitrogen cycle one finds unique groups of specialists who perform indispensable roles. Without them the cycle of nitrogen would be imperfect and the world of life would be limited to those creatures that could employ nitrogen in available non-organic form.

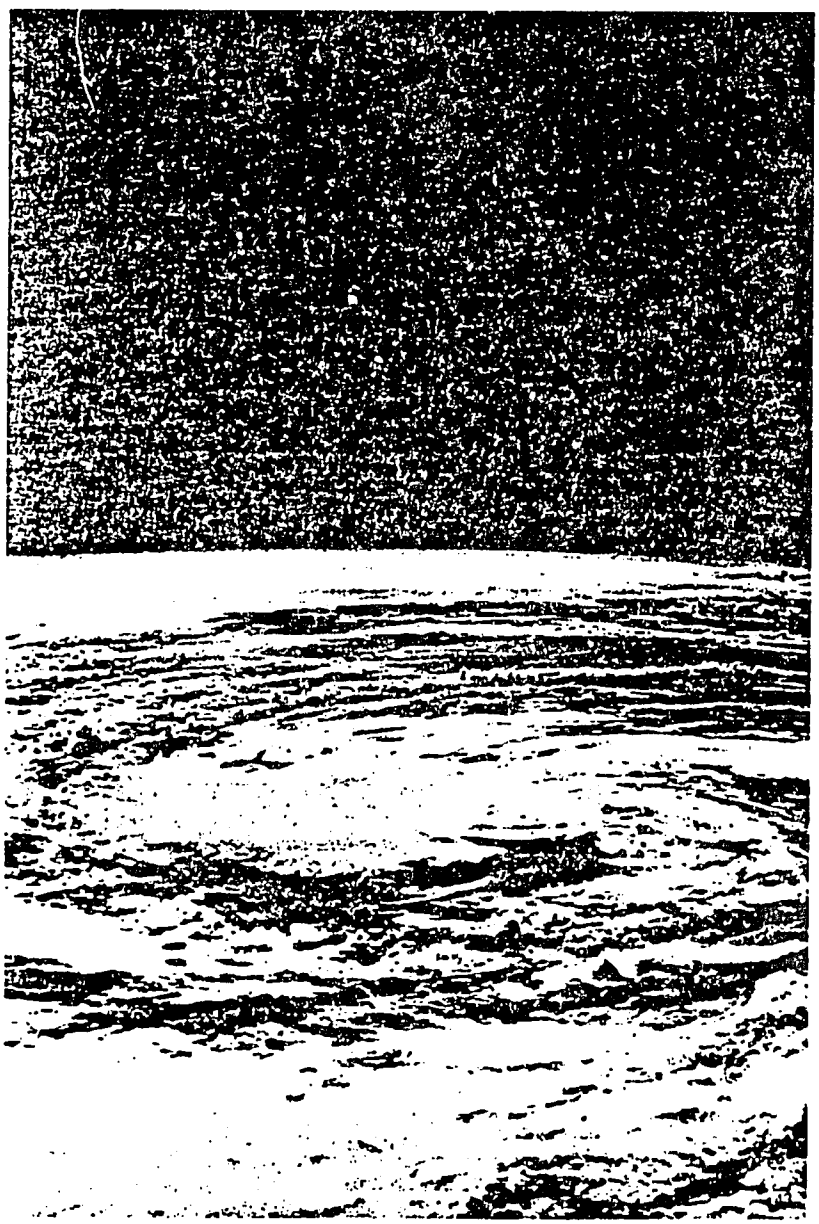
These indispensable creatures, performing their vital role in the nitrogen cycle, deserve to be household words, man's great heroes. Yet sadly those who named them had no thought of public honor and familiarity and called them Azotobacter and Clostridium, Rhizobium and Nostoc.

There remains an unidentified one per cent of matter constituted in organisms. Within this small proportion are many essential elements, including the trace metals, but one of these must be selected for particular attention because of the nature of its cycle. Phosphorus, essential for life, is involved in a system more simple, yet more critical, than nitrogen. The major reservoir is again in the rocks and deposits; it exists in the oceans and in organisms. Like nitrogen it is employed in protein synthesis of plants and

animals. The reservoir in the rocks is supplemented by volcanic apatite and from the excrement and residues of marine birds and fishes. As dissolved phosphate it is used by plants, animals and bacteria, and their excretions, bones and teeth are reduced by phosphatizing bacteria into a form again suitable for protein synthesis. In this cycle there is a continuous loss of phosphorus to the sea and to the oceanic depths where, unless returned by volcanism or upwelling by ocean currents, it is lost to the system. It appears that there is today an imperfection in the phosphorus cycle and that it is not being returned to the system as fast as it is being consumed.

Our understanding is growing: we have added the four major elements, carbon, hydrogen, oxygen and nitrogen and one important minor element, phosphorus, to our company; we have recognized the fundamental importance of some hitherto obscure and unknown algae and bacteria, Nostoc and Azotobacter; we have recognized that volcanic action and lightning are allies rather than enemies; we have learned to fear losses of carbon and phosphorus to the depths of the ocean and to respect water and the ocean as a primary component of the fitness of the environment.

Can we now see these elements, endlessly



recycled, the same finite source moving from the seas into the air, from rocks into solution, deposited and again raised by volcanism, passing through the streams of life, constituted into protoplasm, in the quick and the dead, mobilized in creatures from the beginning and forever? From the heart of volcanoes, from ancient beds of limestone, from high in the atmosphere or from deep in the seas this matter is endlessly recycled—sustaining life, fit for life.

Our identification, even of the major actors of the biosphere, is far from complete if we forget the encompassing envelope that is our milieu: the atmosphere—that membrane around the earth whose gases pervade the seas and the soil and permeate all living things.

> *It would seem universally admitted that the earth's atmosphere is secondary, as is indicated by the extremely low content of the heavy rare gases . . . if by nothing else. It would also seem clear that the first atmosphere could not have contained much CO_2 . . . . It is also reasonably certain that, initially, it could not have contained free oxygen. The most likely constituents are ammonia, giving rise to nitrogen as hydrogen is lost, and methane, which would be fairly stable in the absence of oxygen.* *

Such is G. Evelyn Hutchinson's description of the early atmosphere. It was in this situation, he hypothesizes, that "surface reactions on solids, [in shallow oceans] probably aluminosilicate clays . . . might provide further . . . opportunities not only for organic synthesis but also for incipient biological organization."**

There seems to be reason to believe that the original forms of life were anaerobic, existing without oxygen. There is indeed speculation that bioluminesence—which is most familiar today in the firefly—is a residue of this period when it was necessary for orga-

*G.E. Hutchinson in *The Earth as a Planet*, p. 422.

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nisms to expel an oxygen that was toxic. There is a further and more entertaining speculation to the effect that this same primitive bioluminesence was a precursor of the evolution towards the nervous systems of animals and thus of the human brain, the great oxygen consumer. This suggests that the brain is the descendant of an early waste-disposal system.

There subsequently emerged the plant, consuming CO_2 and expelling oxygen. The product of this photosynthesis was an increase in free oxygen, first in the seas and subsequently in the atmosphere. It was this, with water vapor and CO_2, which reduced the toxicity of radiation and enlarged the arena in which life could exist. Thus it was life which modified the atmosphere; and the atmosphere in turn not only protected but encouraged and sustained life.

Let us think then of the atmosphere as the skin of the earth, the outer membrane of the biosphere. Let us think of the primeval earth when this thin film rose from the oceans, the exhalations of plants and animals, oxygen and carbon dioxide, which with water vapor, passed the life-giving light, but excluded the destroying rays. This bubble expands, rising from the sea to encompass the land and all the earth. This membrane is evolving, as truly as are the skins of creatures, elaborating to sustain more and more complex life. Now it covers us, raised high, this atmosphere of life, our outer membrane, the breaths of ancient lives, protecting and sustaining us, warming, shading, washing with rain, reverberating with thunderstorms charging the earth, modulating the light through days and changing seasons, source of climate and of weather, making the distant stars twinkle—this atmosphere which permeates us.

The chloroplast in the oceans and on land created that atmosphere which could sustain life. It is matter, water, the leaf, and the decomposers, which, with the sun, are the basis for all life now, all life past and the orderings accomplished by all life in all time. The creation of a life-sustaining atmosphere was one of the most important constituents of this evolutionary process.

Henderson observed that the regulatory powers exhibited by the ocean over temperature and alkalinity demonstrated a remarkable similarity to the homeostatic powers of an organism. In man, the maintenance of health permits only a very, very narrow deviation from a temperature of 98.6°F. The level of alkalinity in human blood, determined by CO_2 (as in the ocean) shows an equally small tolerance—forty-four parts per billion are associated with health, one tenth of a part per billion with coma and death.

The oceans maintain uniformity of alkalinity through the same action of CO_2, which tends towards equilibrium with the atmosphere. The temperature of the ocean maintains equilibrium from its mass, from the exceptionally high number of calories water requires to change temperature at all and by evaporation and convection. Both the organism and the oceans demonstrate similar mechanisms which maintain dynamic equilibrium. Does the atmosphere exhibit similar mechanisms? Is it also in some way organic and evolutionary?

Plants expel oxygen as a by-product of metabolism and consume it in respiration; animals consume oxygen and respire CO_2. Thus the availability of CO_2 limits plants; the availability of oxygen and plant protein limits animals and, when the available CO_2 reaches the lower limits, temperature-regulation also inhibits plant growth. Here again is the same self-regulating mechanism as that exhibited by the oceans, described as "organic" by Henderson. The atmosphere, too, then must qualify for this description; it is organic and evolutionary.

As we absorb these fundamental truths, surely they change our image of the world and ourselves. When we see the atmosphere and the hydrosphere as evolutionary, exhibiting the characteristics of organisms, responsive, having self-regulating mechanisms, our conception of the biosphere must expand to include not only the film of living creatures on the earth, but the atmosphere above the extensive oceans as well. Water and air move through all life, the air surrounds and permeates us, the waters replenish that cistern which is ourselves. "The whole evolutionary process, both cosmic and organic, is one, and the biologist may now rightly regard the universe in its very essence as biocentric."* But not necessarily anthropocentric.

But life without death is unthinkable. Given sunlight, nutrients, water and suitable habitats, a colony of plants would so proliferate as to incorporate all available nutrients within itself. As life is defined not only by irritability or responsiveness but by growth, with no further nutrients available, no further life would be possible. Yet, non-growing organisms, encapsulating their own substances without release for use and re-use by the system would starve and die.

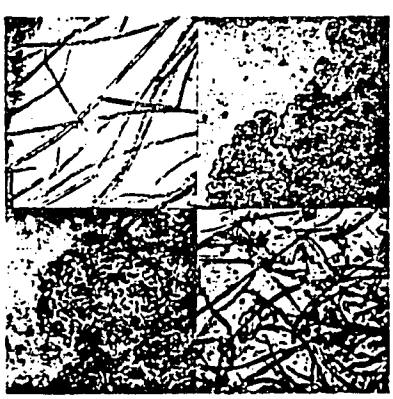
So death is necessary as is the decomposition of wastes and the matter of recent life. When the pathogens and the decomposers reduce the substances of living tissues and reconstitute them into forms usable by other organisms, these—with sunlight and water—make possible the creation of new life, which, by mutation and natural selection, ensures evolution.

The prospect of death begins with life, the span is written in the genetic code. In life the parasites, pathogens and age make incursions within their host while the environment and predators attack it from without. The agents of disease proceed towards death. This is not an instant but a process, in which the carrion eaters, scavengers, insects and their larvae, worms, fungi and bacteria reduce the matter into reusable forms.

Life continues, creatures live, propagate, die,

**Hutchinson, p. 424

*Henderson, 1913, p. 312.



DECOMPOSERS*

*W. Irvine, Microphotographs of sewage fungus and other micro-organisms, *The Biology of Polluted Waters* by H.B.N. Hynes, Liverpool University Press, 1960, p. 96.

their progeny contain mutants and so evolution proceeds. The agents of disease are involved in their death and, with the decomposers, in their destruction and recycling in this return phase of matter to sustain life.

Here the eternal materials of the finite earth, increased by the residues of long dead encapsulations of ancient sunlit creatures, move again and again through plants, animals, wastes and the products of death, constantly recycled by the decomposers.

Decomposers have been described as the return stroke of matter in the cycles of life, some of them are illustrated—not with any hope of widespread public recognition but merely to give some shape and dimension to these indispensable organisms. Few indeed will wish to know their names but these do deserve our honor. The first is an alga—*Stigeoclonium tenue*—followed by *Fusarium aqueductum* and *Carchesium polypinum*. Next is *Zoogloea ramigera* alone and then mixed with *Sphaerotilus natans*, followed by *Beggiatoa alba* and *Apodya lactea*. A massive form of *Zoogloea* follows and in the next illustration is shown highly magnified. The penultimate example is *Leptothrix ochracea* while the last is *Gallionella ferruginea*.

Our list of characters, although still only partial, has become too large for the identification of its essential workman. In the absence of specific recognition and salutation it might be well to extend a general air of appreciation and conciliation to all nature or even better, to begin to understand and act from understanding.

Darwin advanced the conception of biological evolution with natural selection as its primary mechanism. Henderson observed that the earth was peculiarly suited to the evolution of matter and of life, of creatures and of man. Both descriptions of fitness are necessary; they are complementary. Biological evolution still continues, but it does not respond easily to voluntary manipulation while the environment is in a constant flux, inevitably changed by the presence of organisms.

The environment—land, sea, air and creatures—does change; and so the question arises, can the environment be changed intentionally to make it more fit, to make it more fitting for man and the other creatures of the world? Yes, but to do this one must know the environment, its creatures and their interactions—which is to say ecology. This is the essential precondition for planning—the formulation of choices related to goals and the means for their realization.

In the long view one can see the great procession of the evolution of matter and of life, the history and direction of time and life forms. From the precision of evidence comes the poetic license which Wald invokes to speak of the yearnings of atoms as they evolved from hydrogen to the heaviest elements, the compounds as they evolved to the amino acids, unicellular creatures as they evolved to multifarious forms, the yearnings of the earliest tree shrews and their descendants that lead to man, and not least, the yearnings of man.

I can think of no better way of looking at the world and its processes than as if these were a timeless yearning, occurring in a milieu with a proclivity for evolution and for life, in which the environment is fit and may be made more fitting—in which the test is the capacity to adapt the environment and one's self.

There can be no present without a past, no future without both. That which is is only comprehensible in terms of what was. That which was may explain that which is, but cannot predict that which will be.

There is elaborate evidence of that which was in time past. To this we can attend. Much that has been has left evidence of its being. It is written in geomorphology, anatomy, physiology, morphology and cultural

history, although some is too faint to be read. The place and the creature are textbook and teacher, they can speak to him who would and can read.

Perhaps the greatest conceptual contribution of the ecological view is the perception of the world and evolution as a creative process. This can be simply demonstrated by examining the difference between the early earth and the planet as we know it today. Take the mind back to the sterile orb, racked by volcanic action, still lacking oceans. Upon this the energy of the sun fell and an equal amount of energy was lost; this energy was degraded in the process.

Think now of the oceans which developed upon the earth. The sun's rays power both evaporation itself and the transport of the water vapor, which is precipitated upon the earth, moving from high to low elevation. In this process the same energy is employed as before, but work is being performed; the water at higher elevations has a greater potential energy than that in the oceans. Yet all water is proceeding towards its base level as surely as all energy is destined to be degraded. The water acts on land surfaces, and through erosion and sedimentation changes these surfaces towards equilibrium, a condition of repose in which matter moves from a condition of greater to lesser randomness. But, as Paul Sears notes, "while inorganic systems of matter and energy tend towards repose, those which involve life exhibit a countertendency so long as energy is available to keep them going."*

While entropy or degraded energy in any system must increase, in life systems and the orderings that they accomplish, there is evidence, not of degradation, but upgrading, the countertendency which Sears describes. "Energy impinging on living communities and stored in carbon compounds sustains a variety of forms of life, promoting their individual and group organization, enhancing the capacity of the habitat to sustain life, regulating the economy of water movement and chemical transformations—in short doing work."** In this energy is employed with matter through living processes. The energy is temporarily entrapped; it will inevitably be lost to entropy but it will also be replaced. Meanwhile the living creatures persist, evolve and in their beings and their modifications to the earth, act to raise matter to higher orders. This tendency, which is the sum of all life and all time, and the orderings which these have accomplished, is described as *negentropy*. Perhaps it can be given the more affirmative and colloquial title of *creation*—the world's creativity.

We can now see the earth as a process in which energy continuously falls, which inevitably will be degraded, but which through physical processes and life is arrested and entrapped in creatures, raising matter, as evolution proceeds, to higher and higher order. We can see the ordering of physical processes accomplished by precipitation, erosion and sedimentation, volcanism and uplifting, lightning and evaporation, all reducing the randomness of matter essential to this ordering: but overwhelmingly the plant is seen to be the basic agent which arrests and entraps sunlight, the basic agent for the ordering that is negentropy and creation.

Entropy is the rule, it demands its price; all energy is destined to be degraded but physical systems are becoming more ordered on earth, while life systems continue to evolve towards greater order, greater complexity, less randomness—towards negentropy. Abstract, absolute entropy would be that condition when all energy would be degraded, random, simple, uniform, disordered, unable to perform any further work. In contrast, idealized negentropy would exhibit high order, complexity, diversity, uniqueness, ability to perform work. Is this not a description of life and the direction of evolution—it is negentropic—creative.

Can one then imagine negentropy as a tide of ordering, moving deferentially against the force of entropy, paying its tithe, evolving from the order of the nonliving into life, from simple to complex life, from uniformity to diversity, from a small number to an infinitude of species, aspiring to dynamic equilibrium, always imperiled as evolution moves forward? Within this path the cycles of life, death and decay recycle the increasing storehouse of ordered matter, wrested from entropy, through the system. Within the biosphere the creatures in communities and their habitats increase in complexity, in the nature of their symbiotic relationships, in negentropy, evolving—as Teilhard de Chardin has suggested—towards increasing consciousness.

We may now be quite sure, that as men we depend upon the sun, the major elements and compounds, water, the chloroplast and the decomposers. With this new conviction we now turn to the sun and say, "Shine that we may live." We can contemplate matter and say, "From this is the universe, the world and life made." To the oceans we say, "Ancient home, nourish us with water." As the clouds rise from the sea, rains fall and rivers flow, we say, "Nourish us from the sea that we may live." Look to the plants say, "Through you we breathe, through you we eat, through you we live." To the atmosphere we ask "Protect and sustain us." Hold in your hand some soil, know that the essential decomposers are there and say, "Be and work that we may be."

When we do these things, and say these things with understanding, we have crossed into another realm—leaving behind the simple, innocence of ignorance. We can see the world more clearly now, our allies and ourselves. We have formulated a rudimentary value system and we are further on the path to the formulation of a workman's code, the view of the good steward.

*Paul B. Sears, *The Ecology of Man*, Condon Lectures, University of Oregon Press, 1957, p. 44.

**Sears, p. 45.

Source: Sea Frontier, March, April, 1979

Environmental Management in Africa

By THOMAS LAND

MANY COASTAL African countries are coming together to plan regional programs to safeguard their common marine environment and yet still attain maximum economic benefits from their natural resources. Two such schemes—one for the Red Sea and the other for the Gulf of Guinea—have been launched. Many more may follow.

These programs, under the guidance of the United Nations' Environment Program (UNEP), are based on the assumption that the speed of industrialization and population growth in the coastal regions of the developing continents gives planners an opportunity to guide their countries' effect on the common environment. Indeed, such an opportunity in environmental planning and management may never recur.

Consider the Red Sea, a virtually enclosed sea with no industrial complexes and a low population density along its shores. Its only major source of pollution at present is the traffic of oil, restricted until 1975 by the closure of the Suez Canal. But the economists of the region know that the flow of oil wealth pouring into the Arab World is about to bring unprecedented industrial expansion in its wake.

The economic map of the Red Sea is dotted with tiny flags marking the sites of future oil refineries, shipyards, and steel and chemical complexes—all of which, in most countries, discharge their untreated effluents into the sea. These future industrial complexes (and the cities planned to support them) can be built with modern and expensive water-treatment and pollution-control plants that would add to the cost of their products and reduce their competitivity at world markets, or they can turn the Red Sea into a dead pond within a generation.

Coordination of Plans

Already, increased pollution from the oil traffic by the giant tankers, which use the Red Sea as a principal shipping lane, has been recorded in the Port Sudan and the Gulf of Aqaba areas. Both the capacity of the tankers and the overall volume of the traffic may well increase in the years to come, increasing also the daily growth of pollution and the danger of ecological disaster through shipping accidents. Both can be avoided, however, through regional treaties prescribing high antipollution and shipping safety standards, as well as trained personnel to enforce them. A basis of such cooperative action must be coordination in long-term planning.

UNEP's plans for the Red Sea include ambitious training programs for

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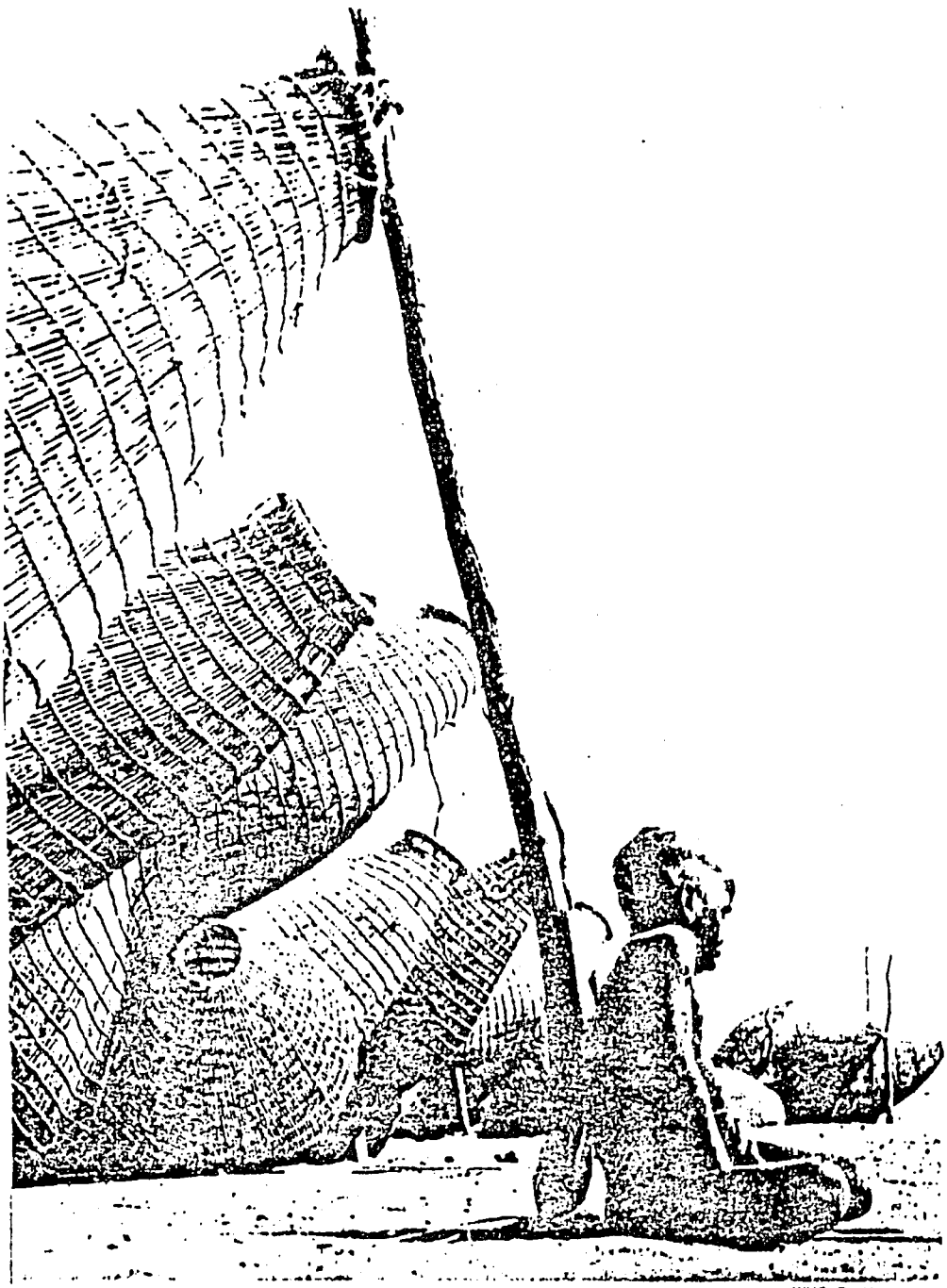

WHO/Dr. Holstein

AN AFRICAN BOY OVERSHADOWED *by primitive fish traps reminds us that future generations deserve the right to an environment unsullied by pollution. Fortunately, world leaders are now making plans for environmental protection in yet-undeveloped areas that are being threatened by the encroachment of industry.*

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THE SAME WATER *that serves for drinking also serves for bathing, laundry, and sewage disposal in many undeveloped areas. In addition, industrialization (lower), although advantageous to the economy, brings its pollution. Action to solve these problems is presently a high-priority task.*

Left above: WHO/B. Cvjetanovic
Left below: WHO/P. Almasy

marine scientists as well as research and pollution monitoring. The Arab League has already brought together the specialists and policy makers of the region (except those of Ethiopia and Israel). They are to meet again early this year in the knowledge that the ecological future of all their countries depends on their ability to harmonize their development plans.

The first part of UNEP's plans for the Gulf of Guinea in West Africa is likely to be completed within two years in a set of protocols embodying a vast compromise of economic interests by 19 countries united in their common need for a clean environment. Like the Red Sea, the Gulf suffers from oil pollution that may well intensify in the absence of international measures. It is also facing a population explosion that is expected to double the number of people in the coastal areas to 24 million in the next quarter century. Untreated human sewage and other forms of pollution are already responsible for economic damage to fishing and tourism.

Pesticides used in agriculture and manufacturing find their way into the sea, according to a recent discussion paper published by the United Nations World Health Organization, which is participating in the scheme. In the water, they undergo sedimentation or are absorbed by filter-feeding marine organisms, and through them they reach man. During 1972, almost 10,000 metric tons of pesticides were used in agriculture by six countries of the region; by 1974, only two countries used nearly as much.

The Choice: Victim or Victor?

The offshore oil fields of Nigeria, Gabon, Angola and, recently, Zaire and the Congo, have contributed to the pollution of the crystal waters of the Gulf. Senegal, Guinea-Bissau, Liberia, Ghana, Ivory Coast, Togo, Sierra Leone, and Cameroon now hope to become offshore oil producers. Most of them have golden beaches polluted with tar balls.

High-pollution industries, such as phosphate, cement, fertilizers, and chemicals, are currently at their advanced stages of planning along the sea coasts and beside rivers leading into the Gulf by Ghana, Togo, Senegal, Cameroon, and Ivory Coast. The sea is discolored for miles around existing plants discharging untreated effluent.

Improving the waste disposal facilities of the existing plants and altering and upgrading the plans for the future industries would necessarily require great financial sacrifice. The industrial planners of the Gulf countries—like their colleagues in the Red Sea area—say that they regard such a sacrifice essential to save themselves from becoming victims of their own economic development. Their example could set a pattern in regional planning. □

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Photograph by C. Springmann (Black Star)

Public concern sparked by the Santa Barbara oil spill in January of 1969 . . .

Photograph by Charles Moore (Black Star)

. . . culminated in demonstrations and protests on Earth Day, 1970 . . .

Photograph by Martin A. Levick (Black Star)

. . . and continued to gain strength right on through Sun Day last spring.

Source: National Wildlife
Vol. 17, February, 1979

National Wildlife's Tenth Annual
Environmental Quality Index

1969-1979 A DECADE OF REVOLUTION

BY GLADWIN HILL

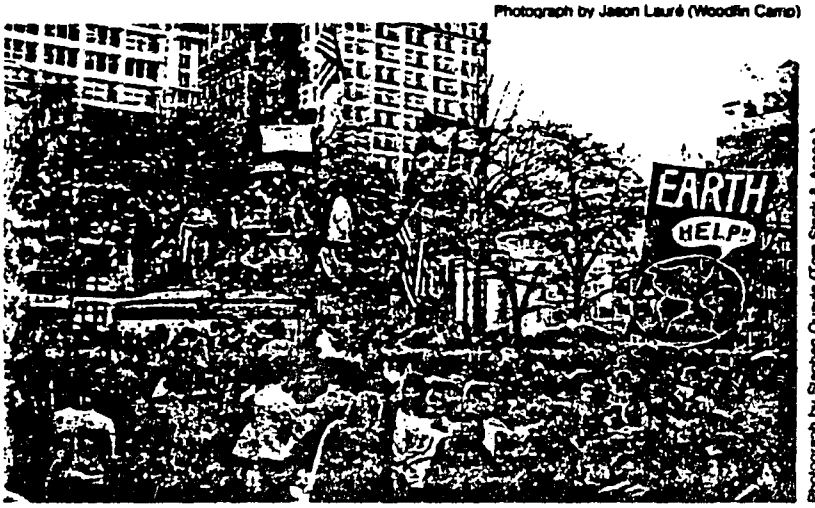
IT is doubtful that anyone who lived during the Middle Ages ever called them "the Middle Ages." Or that participants in the French Revolution said, "Well, here we are staging the French Revolution." Or even that people caught up in the Industrial Revolution ever asked each other, "Hey, what do you think of this Industrial Revolution?" Yet, in retrospect, all of these periods are now seen as major turning points in human history.

Similarly, it is certain that the people of the United States have for a decade been participants, without fully realizing it, in a momentous shift in humanity's course. Some are already calling this change the Environmental Revolution.

A few bemused souls still think of environmental concerns as a

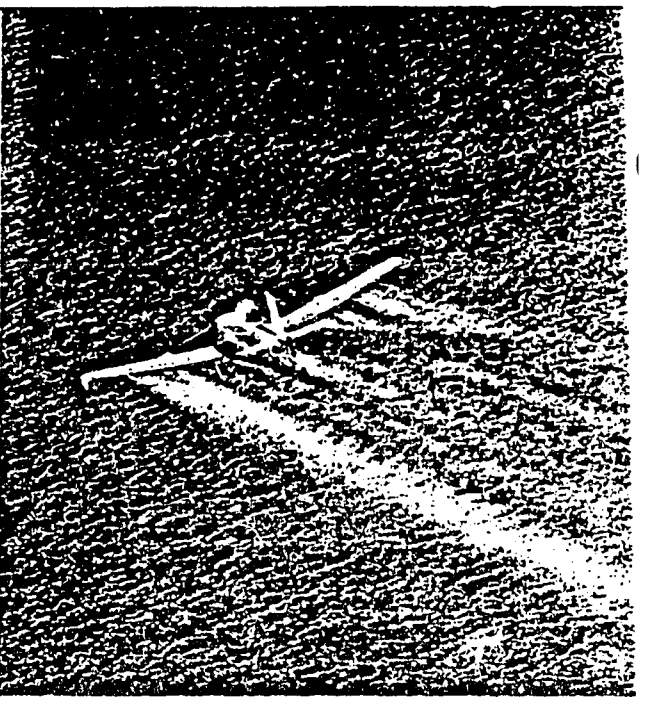
The Decade in Review

Photograph by Jason Laure (Woodfin Camp)



In the streets of New York, and on college campuses all across the country, millions of people gathered in 1970 to mark Earth Day and declare war on pollution.

Photograph by Stephen Ouryle (Tom Sack & Assoc.)



Rachel Carson's *Silent Spring* warned in 1962 of the hazards posed by pesticides. Throughout the 1970s, hundreds of other toxic substances were found in America's air, water and soil.

fad — a transitory spasm of radical assertiveness by bird lovers, fresh-air fanatics and nihilists who would degrade human achievements and amenities in the glorification of Nature. This myopic view is, of course, absurd. It is refuted by overwhelming evidence.

The Environmental Revolution has altered our physical surroundings. Beyond that, it has worked remarkable changes in government, law, politics and economics. It has reshaped many people's philosophy of life and scale of values. In very practical terms, the Environmental Revolution is lengthening lives and lessening human misery by reducing the poisons in our air, water and soil. Perhaps most importantly of all, in a way not too many people have noted, the Environmental Revolution has revitalized the democratic process.

Ten years ago, when the National Wildlife Federation put out the first Environmental Quality Index, the word "environment" wasn't in most people's vocabulary. Then two things happened which, taken together, were like "the shot heard 'round the world" that touched off the American Revolution. One was the offshore oil well blowout at Santa Barbara, California. The other was the astronauts' landing on the moon.

- The oil well blowout stirred international attention far out of proportion to the episode itself. Millions asked: "If something like that can happen to Santa Barbara, how do I know something equally ugly may not happen in my neighborhood — or my backyard?"
- The astronauts pointed their television camera back at the earth, and for the first time we could see our world in true perspective: a small ball of rock and mud, spinning through space, its inhabitants scarily dependent on the thin layer of resources covering its surface.

Russell Train was the first of a series of strong leaders who have prevented the Council on Environmental Quality from becoming a rubber-stamp agency.

Photograph by F. Ward (Black Star)

People suddenly looked around in 1969 and saw oil wells being drilled hither and yon, forests being chopped down, rivers being dammed, highways being rammed through parks and wetlands, wildlife being exterminated, lakes, becoming saturated with refuse. They asked: "Who's in charge here?" And the answer was: "Nobody."

A funny thing had happened on our way into the twentieth century. We Americans became so obsessed with the blessings of technology and material growth that we overlooked the adverse side effects. At the same time, we forgot that democracy depends on citizen input. The Environmental Revolution represented an abrupt turnabout. There was a tidal wave of public concern, a new spirit that gave birth in 1969 to one of the most remarkable pieces of legislation ever enacted: the National Environmental Policy Act.

This law doesn't forbid anyone to do anything. All it says, in essence, is that before we embark on any federally funded project that may affect the environment, we must consider the consequences. It's the irrefutable wisdom of "look before you leap," and this simple concept very quickly became the cutting edge of environmental reform.

The environmental-assessment process prescribed by the law has been the nemesis of those who would revert to the boomtown ethic of reckless exploitation. Because of it, scores of questionable federally aided projects have been cancelled, and hundreds more have been modified. Today, the word "environment" is a part of nearly everyone's vocabulary, and environmental considerations are an established factor in public decision-making.

It took a series of minor miracles to bring all of this about. The National Environmental Policy Act might have been just a scrap of paper without the Council on

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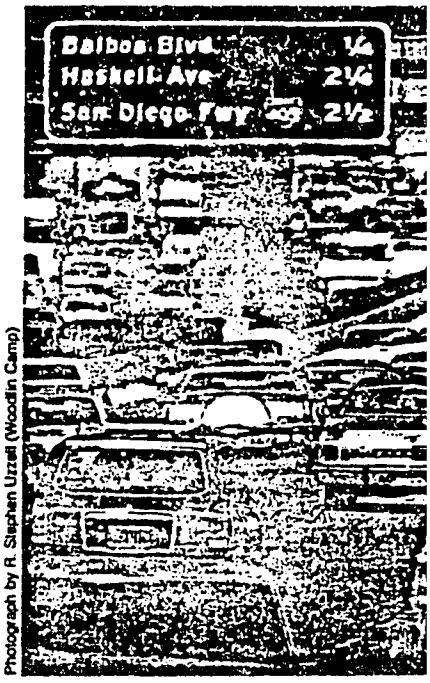
Photograph by Mark Wexler

The surging environmental spirit of the early 1970s produced the action-oriented Youth Conservation Corps and other outdoor programs.

Photograph by Lynn M. Stone

With the passage of the Endangered Species Act in 1973, animals like the crocodile gained the protection needed for recovery.



Photograph by R. Stephen Uzzell (Woodfin Camp)

Tough federal laws have forced polluters to clean up the nation's air, but auto emissions remain a major health problem.

Environmental Quality (CEQ) to implement it. CEQ might have been just another rubber-stamp agency without a succession of strong individuals at its helm, from Russell Train and Russell Peterson to Charles Warren. The public's environmental concerns could not have found practical expression without the creation of the Environmental Protection Agency (EPA), which itself would have been doomed to impotence without its own succession of hard-nosed head men — William Ruckelshaus, Russell Train and, now, Douglas Costle. Finally, no amount of diligent leadership could have mobilized the EPA if it had not been cast as something quite revolutionary in the first place.

From the nation's beginnings, it had been the practice to establish cabinet departments and federal agencies serving special interests. The Department of Agriculture served farmers, the Department of Commerce served businessmen, and so on. Over the years, these agencies became a catchall for regulatory duties. The addition of these functions to promotional responsibilities in many cases caused grotesque conflicts of interest. Agriculture was expected to promote pesticides on the one hand and limit their use on the other. This schizophrenia had reached an Alice-in-Wonderland stage by the time the EPA was established as a neutral custodian of all regulatory powers bearing on the environment.

Pollution was the preoccupation of the earliest years, but the environment's dimensions were soon seen to be far broader than that. They encompassed resources, recreation, population, land use, law, politics and economics. As early as 1970, environmental issues were figuring in political defeats and victories, and they were a prominent facet of Jimmy Carter's presidential campaign.

The Environmental Decade has produced most of the basic legislation needed for environmental reform. The accomplishment of this, in the face of massive lobbying and obstruction by vested interests, is a tribute to the doughty corporal's guard of environmental lobbyists, to the National Wildlife Federation and its affiliates, and to various other conservation groups.

But momentum could not have been sustained without a constituency that includes most of the nation's citizens. The public has been able to get into decision making at all levels of government: by attending hearings; by commenting on proposed actions, as provided for in the National Environmental Policy Act; by circulating petitions, writing letters, making phone calls, organizing campaigns; and, by bringing citizens' lawsuits into the nation's courtrooms.

Photograph by Doug Bruce (Camera 5)

William Ruckelshaus was cast in a monumental role in 1970: head of the new Environmental Protection Agency.

Only a small minority of citizens can be called environmental "activists." Many people get excited only about local issues, ignoring federal and regional developments of great import. But year after year, national opinion surveys constantly reveal a solid mass of public support for improved environmental quality.

For American industry, the Environmental Revolution has meant a radical rule change in the middle of the game. Industry traditionally used waterways as sewers, vented limitless fumes into the air and gouged up the landscape to procure raw materials. Then, all at once, these things were outlawed.

Industry's first reaction was predictable enough. It contended that pollution abatement was too difficult and too expensive. Both objections have been largely demolished, and by now industry, broadly speaking, has

Gladwin Hill is the national environmental correspondent of The New York Times.

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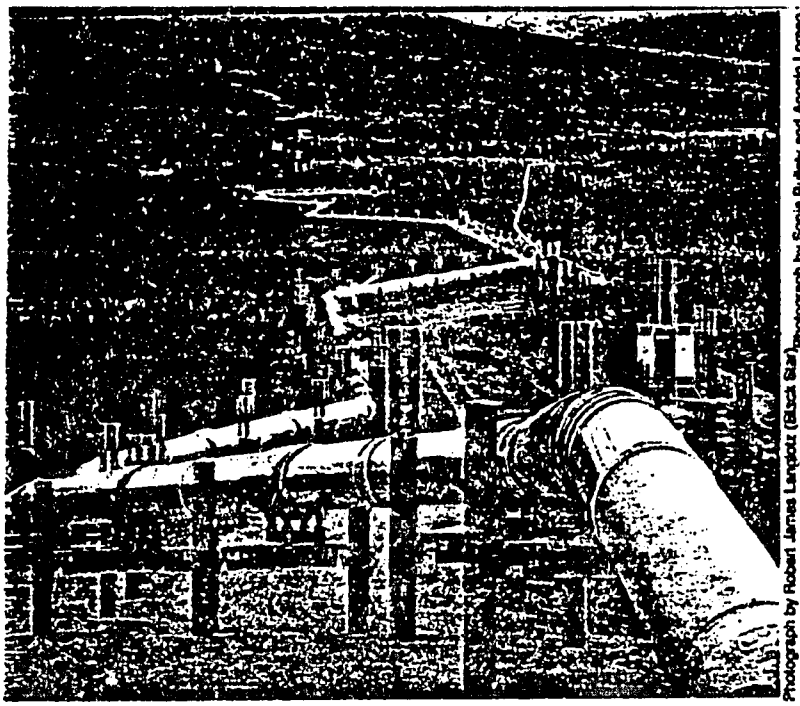
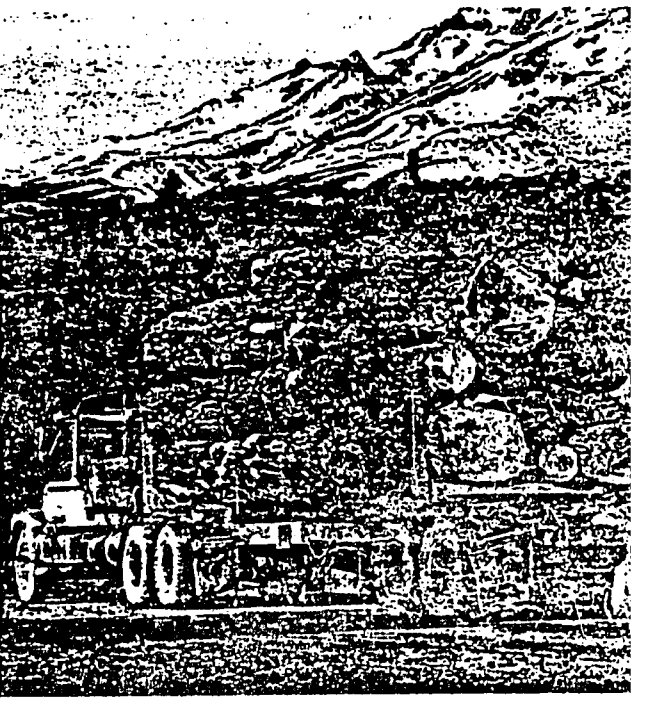


Photograph by Robert James Langdon (Black Star)

Flexing their political muscle, environmentalists engaged in a five-year fight to improve the design of the controversial Alaska pipeline. In the end, they brought about significant changes.



Photograph by Sonja Bullaty and Angelo Lomeo

Last-ditch efforts by conservationists saved California's Redwoods National Park, but, elsewhere, unregulated urban sprawl continued to gobble up unprotected U.S. lands.

moved into the mainstream of environmental reform — albeit too often after detours through the courts.

This is not to say that Valhalla is just around the corner. We still have a long way to go, as the resource rundowns on pages 22-31 of this report amply document. Most of the nation's environmental problems have not been "solved." Oilmen still have the itch to drill with no holds barred. The forest products industry wants to harvest still more timber in the national forests. Strip miners are contesting new reclamation requirements.

There are still pockets of resistance to the most elementary cleanup requirements. Hoary assertions still resound equating environmental improvement with unemployment and inflation, even though it has created many new jobs for every one it has eliminated — and even though repeated studies have shown that environmental expenditures' role in inflation is minuscule. But it does not seem Pollyannaish to look back and be heartened by the overall contrast between the situation a decade ago and conditions now.

Long before the Arab oil embargo, for example, environmentalists foresaw an energy crisis. Calls for fuel conservation and "clean" energy alternatives punctuated Earth Day in 1970. Some interests tried to blame the energy pinch on "environmental constraints," and they have fought long and hard to change the new laws and regulations. Today, there are still many points of conflict between all-out energy production and environmental protection. But it has become increasingly apparent that between these goals there is ample leeway for sensible accommodation.

Concerned celebrities like Robert Redford, a National Wildlife Federation director and Wildlife Week chairman, helped to mobilize support for environmental programs.

Photograph by Adam Scull (Black Star)

The Environmental Revolution has been full of surprises. We started out thinking that DDT was our main chemical problem. But DDT turned out to be only a thread that, when pulled, unraveled a whole skein of evil, from PCBs and other dioxins to Kepone and a still-lengthening roster of other poisons.

Water pollution initially was attributed almost entirely to sewage plants and industry. The solution seemed to hinge on the installation of billions of dollars in hardware to purify effluents. Now we know that water pollution is also caused by "nonpoint" sources — everything from urban and farm rain runoff to atmospheric fallout — and we know that expensive hardware is not the full answer to this problem. Pollution technology is shifting, therefore, to more natural methods, such as lagooning and aeration.

Sludge disposal was once considered the least of sewage treatment problems. Now it is looming as a severe one.

Solid waste and noise were once classified as the simplest of the pollutions to deal with; they have long since proved to be perhaps the most intractable.

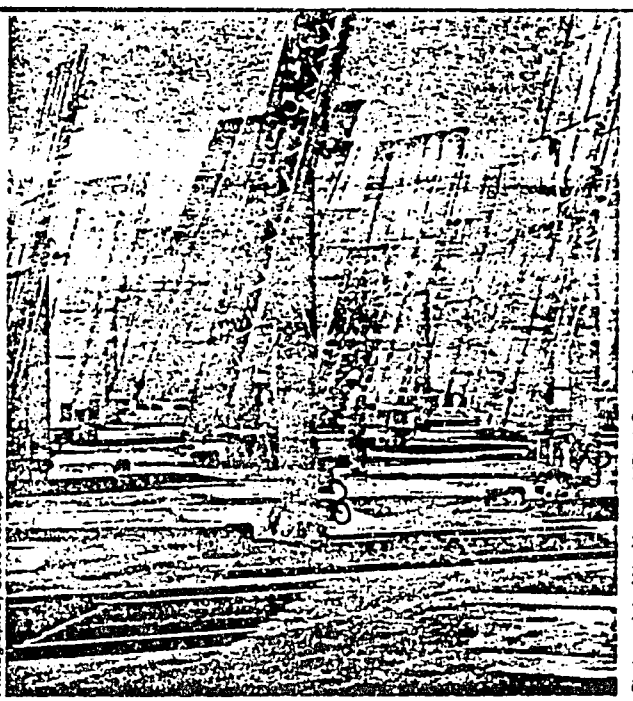
Land use, the underlying element in most environmental problems, seemed the logical starting place for corrective measures. But aside from coastal zone management, no national land-use plan has made it through the Congress.

Yet another surprise has been the way environmental arguments repeatedly have saved the day when the main issue seemed to be something else:

- The U.S. supersonic transport program was an economic deadfall, but objections to noise, fuel gobbling and stratospheric pollution were the issues that blocked it.
- The Alaska pipeline, as originally designed, was technically very faulty. Delays for environmental assessment gave time for corrections.
- After litigation over the endangered snail darter halted the Tellico Dam project in Tennessee, the U.S. General Accounting Office came to the conclusion that it was economically unsound.

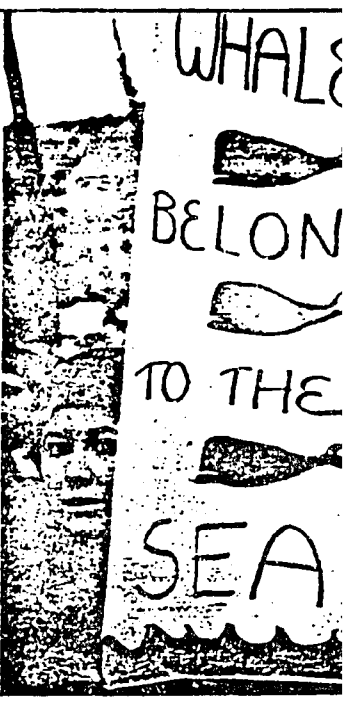
Photograph by Ted Spiegel (Black Star)

1972, Uncle Sam told water polluters to stop discharging by 1985. Some progress has been made, but that deadline may not be met.



Photograph by Steve Northup

Outside of war and assassination, few events have jolted the American people as rudely as the 1973 Arab oil embargo. It underscored the need for conservation and solar energy.



Photograph by Mike Mazzaschi (Stock Boston)

Whether to save whales or stop a polluter, the revolution continues apace.

• Environmentalists' apprehensions about atomic power slowed down its expansion even as constrictive economics were beginning to close in.

The Environmental Revolution, seen in the perspective of ten years, clearly has not been an isolated phenomenon. The 1960s was a decade of protest, when a whole spectrum of national institutions and preoccupations came under fire. These concerns ranged all the way from the Vietnam War to packaged cereals. The big impetus for Earth Day came from college campuses, and it was, in some respects, a benign transmutation of the energies that had so recently gone into antiwar rioting. Gradually, the "hippie" connotations of environmental protest fell away. Thoreauvian simplicity, respect for nature and concern for the quality of life persisted and spread from young people to the older generations.

The spirit of popular protest that coalesced environmentally after Santa Barbara stayed alive through the denouement of the Vietnam War, and then persisted again through the maelstrom of Watergate. It continued to grow and flourish throughout the mid-1970s. By now, the Environmental Revolution — once derided as an aberration of bird watchers — has come into full focus as part of an even greater wave of history. It was a revitalization of the democratic spirit that generated environmental concerns, and that thrust is sustaining them even now.

Efforts at any particular juncture to assess the state of the environment in terms of "progress" vs. "backlash" don't seem too meaningful. The battle goes on in thousands of sectors everyday, bringing both advances and setbacks. It is a battle that never will be won, because it essentially is a process: the process of reconciling man's boundless ambitions with nature's inevitable constraints. It is a battle that cannot be lost so long as the democratic spirit persists.

Beginning on the next page, the editors of NATIONAL WILDLIFE assess trends and developments affecting the nation's major natural resources in the past ten years.

Agenda for the next decade

• *Complete the cleanup of the nation's rivers, lakes and coastal waters.*

• *Press for abatement of air pollution; develop practical alternatives to the internal-combustion automobile engine.*

• *Implement the toxic substances control program.*

• *Develop comprehensive recycling of solid waste under a price structure incorporating the hidden costs of resource depletion.*

• *Muffle noise — before it drives everybody crazy.*

• *Pinpoint the precise effects of high-voltage radiation, from power lines to microwave devices.*

• *Step up the transition to a new national energy pattern: develop solar, wind and tidal power, coal gasification and liquefaction. Resolve controversies over the safety and economy of nuclear power. Produce a system of radioactive waste disposal.*

• *Develop national land-use guidelines that will aid population distribution, facilities siting and community growth. Institute permanent protection of coastlines for public enjoyment.*

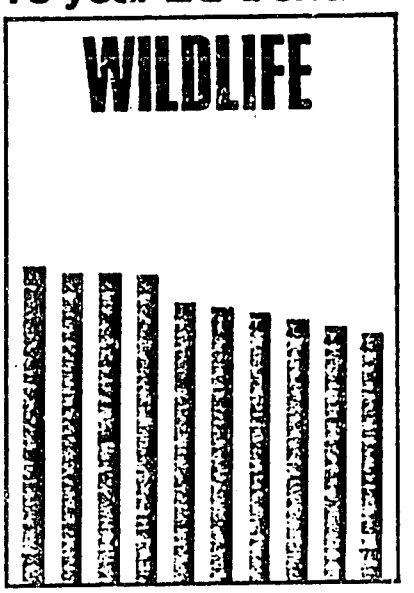
• *Coordinate the management for maximum public benefit of federal land (one-third of the nation's area) now fragmented among the Forest Service, the National Park Service, the Bureau of Land Management and the Bureau of Reclamation. Advance wilderness and wild rivers' preservation from the discussion stage to the preservation stage.*

• *Develop explicit preservation-vs.-use policies and practices for the national parks, and decide who's to create and operate urban parks.*

• *Develop a national consensus on the preservation of endangered species and a mechanism for implementing it. Resolve the vendetta of conflicting interest groups over "predator" extermination.*

10 year EQ trend

Photograph by Mark W. Kelley

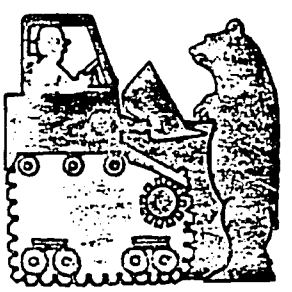


Many battles have been won, but the war is far from over

TEN YEARS AGO, the U.S. was celebrating its first lunar landing, and the welfare of wildlife back here on earth remained a comparatively obscure public issue. It was not for lack of problems; they were plentiful enough. On the high seas, some whales were being commercially hunted almost to the point of extinction. In the continental U.S., populations of brown pelicans, eagles and peregrine falcons were being devastated by chemical residues. More than 1¼ million acres of prime wildlife habitat were being destroyed annually for development and highways. Most of the Great Lakes fisheries had already been tainted by pollution. There were no effective national programs for saving endangered animals.

Losing ground

Urban sprawl, strip mining and farming are gobbling up wildlife's living space.



"Wildlife often shows the effects of pollution first," NATIONAL WILDLIFE said in its first EQ Index. "Dirty water kills millions of fish every year. Increased use of pesticides is having a harmful effect on the breeding potential of our birds of prey and possibly other forms of life — including humans."

A decade ago, most Americans didn't even know the meaning of terms like "habitat" and "food chain." The notion that man's fate is linked with that of the wild kingdom had not yet caught the public's fancy. But it would — and soon.

Where do we stand today? Since Earth Day, wildlife has become an increasingly popular issue. This mounting public concern has helped to move some important new laws through Congress — laws that relate specifically to improving wildlife's lot. They touch on everything from strip mining and rangeland to forest habitat, coastal wetlands and endangered species. Now, conservationists have more leverage to fight projects and policies harmful to wildlife.

Such challenges have forced government agencies to adopt new guidelines for managing wildlife in the nation's forests and rangelands. For example, the Bureau of Land Management (BLM) has tried to clamp down on off-road vehicles to reduce habitat destruction. The Forest Service (USFS) is taking greater pains to protect wildlife from the adverse effects of logging. Many conservationists applaud these efforts, but others lament their "inadequacy." Getting federal agencies to change their programs to aid wildlife, complains the well-known biologist A. Starker Leopold, "is like pulling teeth." Livestock overgrazing on BLM lands, for instance, remains one of the worst problems for wildlife in the West.

Wildlife trends

Despite habitat losses, wildlife managers have helped many species.

	UP	DOWN
DEER		
ANTELOPE		
DUCKS		
GEESE		
ALLIGATORS		
GRIZZLY BEAR		
BEAVERS		

Some major victories have been achieved for wildlife in the courts. The Alaska pipeline was not stopped, but it was modified so migrating caribou could cross it. A scheme to dig a canal all the way across Florida was stopped. The Corps of Engineers was ordered stop building a North Dakota drainage dite that would have destroyed the nesting ra of thousands of migratory waterfowl. Another court order stopped constructi of a dam and reservoir on the Laram River in Wyoming that threatened "critical habitat" of the endanger

WORSE SAME BETTER

WILDLIFE · 10 YEARS LATER

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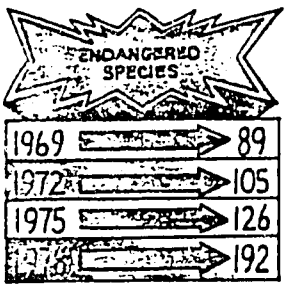
whooping crane.

Projects like these have devoted boosters in Congress and elsewhere. As a result, many torpedoed boondoggles keep bobbing back to the surface. In 1977, the enormous pork-barrel power of Congress rose up for the whole country to see when President Carter tried to kill 18 ill-advised water projects; eventually, a number of them were restored. In 1978, however, the public's aversion to taxes and government spending was turned against the dam builders, and President Carter's landmark veto of the public works appropriations bill was sustained by a wide margin.

Creatures in peril

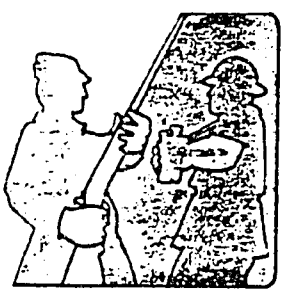
The U.S. has identified more and more animals in trouble.



Last year, a classic confrontation between wildlife and the dam builders ended up in the U.S. Supreme Court. The question was whether the Tellico Dam should be completed on the Little Tennessee River, even though it was economically unsound and could wipe out an endangered fish, the snail darter. Environmentalists said no and the court agreed. But the controversy over that case helped to generate so much congressional pressure that the endangered species law itself was softened.

Who speaks for wildlife?

Disputes between "users" and "watchers" have not helped wildlife's cause.



The impact on wildlife of these and other developments is difficult to gauge in the perspective of just a few years. Certainly there have been many promising signs. The wild turkey, once seemingly on the verge of extinction, has recovered to the point where it is now found in 47 states. Atlantic salmon are again running in some New England rivers. There probably are more deer now — some 14 million — than there were before the coming of the white man. Encouraging gains have been noted for alligators, whooping cranes, brown pelicans, ospreys, eagles, pronghorns and bighorn sheep. Numbers of ducks, songbirds and squirrels are generally up — at least for now.

Other creatures, however, are not faring nearly as well. Some 225,000 lesser sandhill cranes are in a precarious predicament as western farms, factories and homes continue to suck their wetlands dry. The endangered species list has grown to 192, and 64 "recovery teams" are trying to save them. Still, at least one species didn't make it: the Tecopa pupfish of California was removed from the list because of probable extinction. And one of the last surviving Florida panthers was illegally shot in 1978.

Wildlife management has been responsible for many of the gains, but in recent years these achievements have been partly obscured by dissension within the conservation community. Some people who oppose hunting, trapping and even fishing argue that wildlife should not be killed for sport, even to thin "surplus" animal populations. Nature, they say, should be allowed to "take its own course." The trouble with that, biologists point out, is that nature's way has been upset by roads, shopping centers, pollution and the removal of natural predators. Only scientific management can compensate for these disruptions.

Other controversies have led to reevaluations of a number of federal programs. Among these: control of predators and the management of free-roaming horses and burros. A program to phase out toxic lead shot used by waterfowl hunters has been another "hot issue."

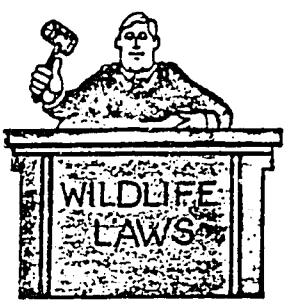
Arguments over wildlife often boil down to dollars and cents. Historically, sportsmen have shouldered the burden of wildlife's costs through state and federal fees. This money has gone for everything from new refuges and fish hatcheries to transplant programs designed to restore elk and bighorn sheep to parts of their former ranges. One thing nearly all conservationists agree on now is the need for new sources of funding. But so far, schemes for general appropriations and excise taxes on things like birdseed and camping gear have not made it through Congress.

Our toughest challenge? We need to slow the rate of habitat loss. Some gains have been made: the National Wildlife Refuge System has grown from 30½ million acres in 1969 to nearly 34 million in 1977. The system could *double* with the addition of new lands in Alaska — but the Alaska lands bill did not make it through Congress last year. The U.S. Fish and Wildlife Service (FWS) has acquired two million acres of wetlands since 1961, and plans to double that in the next eight years. Wildlife habitat is included in land set aside in federal and state wilderness and scenic rivers.

Still, the job ahead will not be easy. More than 2 million acres of strip-mined land needs to be reclaimed, while nearly 800,000 additional acres are being mined each year. About 2½ million acres of cutover national forest must be replanted. Wetlands are being drained at the rate of 138,000 acres annually, and pollution is ruining too much of what's left. As the nation continues to grow and develop, the pressure on habitat will continue to increase.

New laws help

Since 1969, many new wildlife laws have been enacted.



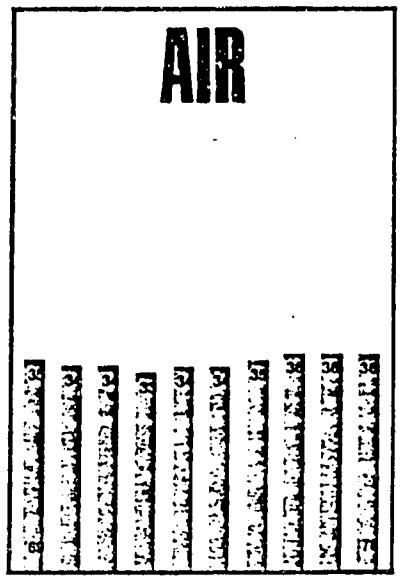
One essential step: more habitat must be set aside to help compensate for land lost to necessary development.

What does this mean to your family? Hunters and fishermen can expect higher license fees and even more stringent regulations as managers try to get the most wildlife on the least habitat. Bird watchers may find waiting lines at refuges during peak migrations. Campers, hikers and canoeists probably won't be as free to roam at will on public land in fragile habitats.

Wildlife will continue to serve as a dramatic indicator of pollution. New York State recently released coho salmon into Lake Ontario. When the fish return to spawn and die, the amount of the toxic chemicals in their fat will indicate how contaminated the water is. By now, just about everyone realizes that a world unfit for wildlife is also unfit for man.

10 year EQ trend

Photograph by David Muench

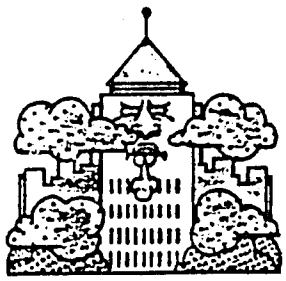


The air is cleaner . . . but is it fit to breathe?

TEN YEARS AGO, the U.S. knew it had an air pollution problem, but it didn't know how serious the problem was or what to do about it. The EPA did not yet exist, and there were no strong federal cleanup deadlines. Good data on dirty air was nonexistent, and individual states were left pretty much to their own devices. The result was predictable enough: hardly anything was done.

Urban grime wave

Out of 105 cities, only Honolulu has air that's considered healthful.



In its first EQ Index, NATIONAL WILDLIFE warned: "Air pollution is probably the most serious threat to our environment. It is a silent killer that hovers over every city. It is a frightening kind of pollution that colors our skies, burns our eyes and blackens our lung tissues."

Heading a list of the nation's dozen dirtiest cities back in 1969 were New York, Chicago and Philadelphia, with Los Angeles, Cleveland and Pittsburgh not far behind. But pollution was no longer strictly an "urban problem." Unhealthful air was menacing whole sections of the U.S.

Where do we stand today? Some real advances have been made, but most of them, concedes one U.S. official, "have just kept things from getting worse."

Since 1970, tough federal air pollution standards have been in force, and each state has developed its own strategy for meeting them. A nationwide network of nearly 7,000 monitoring stations has been set up to keep tabs on pollution levels. Nearly 90 percent of all major U.S. factories are complying with pollution laws. This, unquestionably, has produced cleaner air.

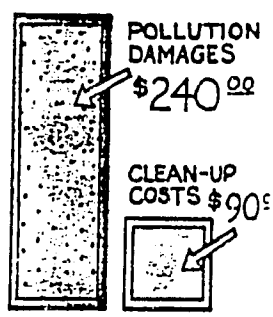
Most Americans, however, live in areas where it is still unsafe to breathe. Out of the nation's 105 largest urban areas, only Honolulu has really clean air, according to the EPA. What's more, smog remain a serious problem in nearly a fourth of the country's 3,200 counties. The reason? The newer cars produce more smog-causing pollution than they were expected to.

Despite that alarming development, the levels of other automobile pollutants have declined. In most urban areas, for instance, carbon monoxide pollution has steadily dropped at a rate of six percent annually since 1970.

Our toughest challenge? With many power plants and factories now converting from oil to coal, holding the line on clean air standards has become a major issue. The EPA is under intense pressure to relax its antipollution requirements.

Costs less to clean u

In the long run, it will cost less to clean up pollution than to put up with it.



What does this mean to your family? If you live in Maine, you are experiencing that state's first ozone alerts. This pollution comes from cars and industries located to the west. If you live in Los Angeles, you experienced your first mandatory antipollution measures last summer, when choking smog closed down businesses and forced people indoors.

This year, Uncle Sam is spending about $90 on air clean for each member of your family. Still, air pollutio may be costing your household about $240 a ye in terms of damages to health and property. According to one recent study, dropping pollu to safe levels from factories and power plants alone this year would produce seven percent decline in illness and death, and save $16 billion in health co

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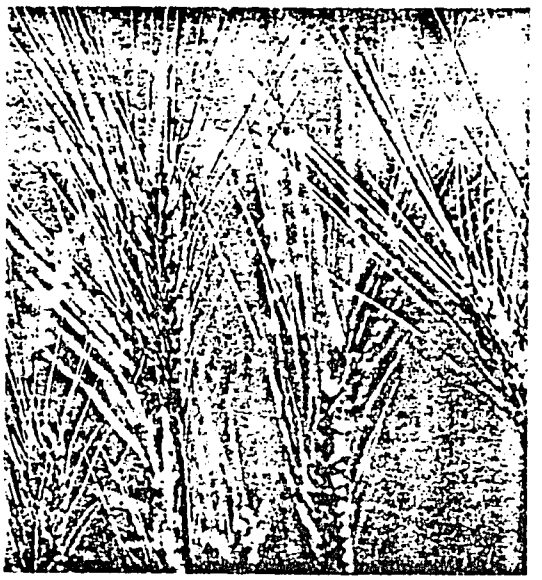
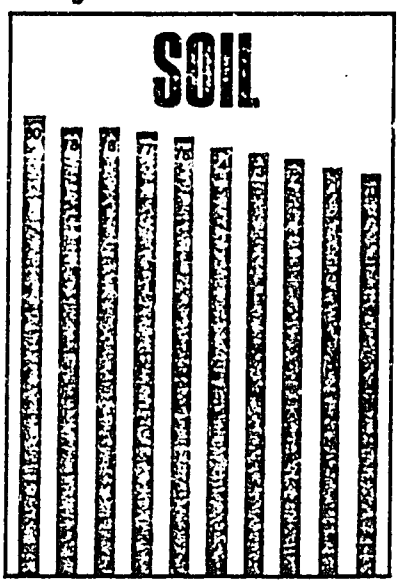
10 year EQ trend



Photograph by David Muench



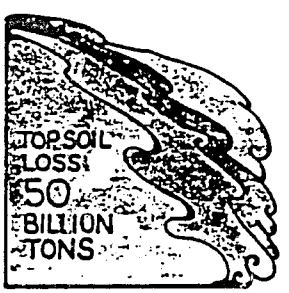
We're farming more land . . . and losing more

TEN YEARS AGO, this country's frantic efforts to conserve its soil — efforts begun back in the Dust Bowl days — *seemed* to be paying off. But although farmers were producing huge yields year after year, all was not well with the land. "Erosion continues to take an enormous toll," the first EQ Index warned. "The U.S. Soil Conservation Service estimates 180 million acres of cropland are affected by wind and water erosion at a staggering loss of $1 billion worth of topsoil annually."

Where do we stand today? If anything, the pressure on soil — often called "America's Number One Resource" — is even worse now than it was a decade ago. Reason: worldwide there are 900 million more mouths to feed than ten years ago. More protective grassland has been plowed up, in part so the U.S. can export $25 billion worth of food annually.

Losing ground

Expensive U.S. conservation programs have not slowed the rate of erosion.



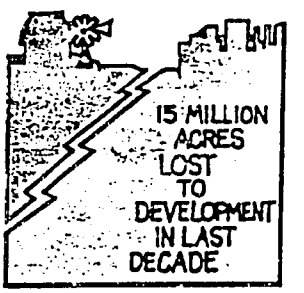
In the last 200 years, we've lost about one-third of our topsoil to erosion. Even since 1935, 100 million acres have been damaged so badly they cannot be cultivated; on another 100 million acres, more than half the topsoil has been lost to erosion.

During the past decade, we've lost 17 million rural acres — gobbled up for highways and reservoirs or covered by concrete in subdivisions, shopping centers and parking lots. Now, a dramatic turnabout in national population patterns is threatening to make this land drain even worse. With the onset of the Industrial Revolution 200 years ago, Americans began migrating from rural areas to the cities. But the trend is now shifting. And today, the highest growth rate is found in rural and semirural areas.

State and county governments are experimenting with various ways to save prime farmland: some 40 states have legislation enabling agricultural land to be taxed at a lower rate than adjacent commercial land. Counties and states are trying to buy "developmental rights" to keep farmlands producing.

Asphalt pasture

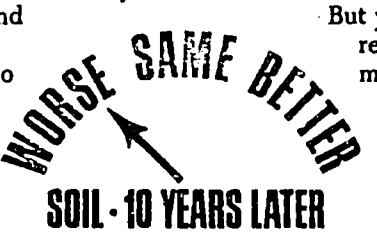
Buying up "development rights" is one way to curb loss of cropland.



Our toughest challenge? Somehow, erosion must be controlled, and prime cropland must be saved to produce food by encouraging soil conservation practices such as minimum tillage, strip-cropping and terracing. It's not easy! Government programs often do not work as well as expected, partly because farmers discontinue beneficial soil practices after contracts with the government expire.

What does this mean to your family? First, despite our soil problems, you should thank your lucky stars you live in the U.S., because you can buy more food of higher quality with less work than the people of any other nation. Some examples: a Russian must work 10 times as long to buy a pound of sugar as you do. A Japanese must work 12 times as long to buy a pound of steak. In Ghana, the average family spends 63 percent of its income on food; in America, the comparable figure is 16 percent.

But your food bill is probably going up for three reasons besides inflation: (1) Surging population means more demand for food. (2) The U.S., still an oasis in a world of want, nevertheless continues to lose soil productivity because of erosion. (3) We've still not really faced up to the problem of saving prime farmland from the bulldozer.



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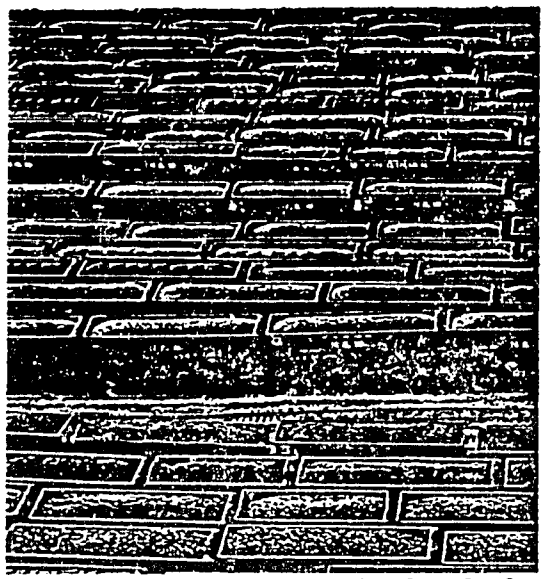
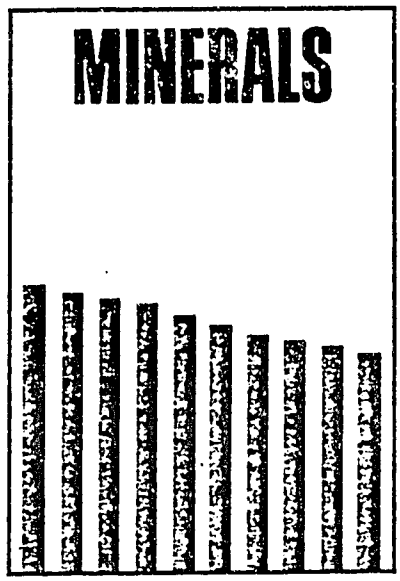
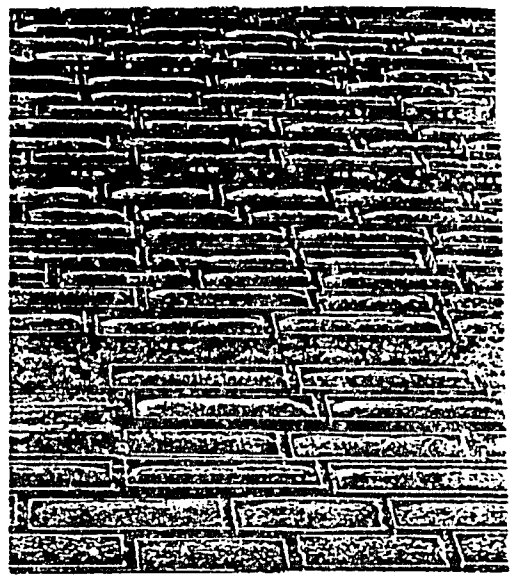
10 year EQ trend



Coal cars photograph by Chuck Rogers (Black Star)



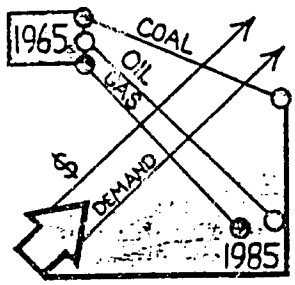


We're moving, too slowly, toward a sustainable society

TEN YEARS AGO, energy was cheap, minerals seemed abundant and the American life-style was more extravagant than ever. With only six percent of the world's population, the U.S. was using a third of its energy. The "throwaway" era was in full flower. There was some concern about the litter problem, but there was not much serious talk about "waste management" and "resource recovery." "When minerals are depleted, they are gone forever," NATIONAL WILDLIFE's EQ Index warned a decade ago. "Yet we burn up fossil fuels and gobble minerals as if the supply were infinite. A new national policy for the acquisition and use of our minerals is urgently needed. The energy crunch is almost here."

Bottom of the barrel

As reserves dwindle, what's left costs more.



In those days, it was easy to dismiss such dire predictions. After all, the nation began this prosperous century with boundless supplies of everything from iron ore and coal to copper, lead and zinc. It wasn't long before wildcatters were discovering vast new oil fields. When readily available domestic mineral reserves finally did begin to peter out, we still controlled enormous foreign reserves and most of the rest belonged to friendly nations. So why worry?

The Arabs supplied a pretty good answer in 1973. With the imposition of the oil embargo, the old "energy crunch" forecasts came true with a vengeance. There were lines at gas pumps everywhere. Fuel costs skyrocketed. A new 55 mph speed limit was enforced nationwide. The economic consequences were profound — dislocations rocked the entire world. Perhaps most significantly of all, in the long run, the oil cutoff forced Americans to think seriously about conservation. Where once there had been complacency, now people were uncertain and talked of "limits to growth."

Top of the heap

Americans throw away 70% of all metal after it is used just once. And problems created by the open dump are unmanageable.

Even at that, there was an initial refusal to bite the bullet. Instead, we were off on a frantic search for quick-fix solutions. "Project Independence" predicated a massive drive to discover new domestic oil supplies and new technologies for getting at them. More money was plowed into nuclear power plants. Old King Coal made a triumphant return and clean-air constraints came under heavy fire.

But the quest for oil independence was doomed. In 1975 U.S. imports exceeded domestic production for the first time in history. The country was increasingly dependent on foreign countries for other raw materials, too.

Where do we stand today? The broad outlines of what the country must do are clear, but action has been slow. The opportunity to capitalize on the impetus provided by the oil embargo is being frittered away. In some respects, we've come full circle — from complacency to panic back to complacency. This can be seen in developments large and small:

- The 55 mph speed limit is no longer widely enforced or obeyed.
- Energy use is still rising too rapidly, though not as steeply as in the pr embargo days.
- Industry has effected some very significant energy savings, but gasoli

WORSE SAME BETTER

MINERALS · 10 YEARS LATER

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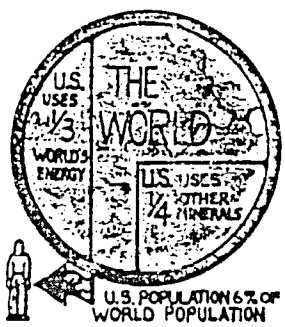
consumption by motorists has continued to edge up, despite the small-car trend.

• In 1977, a new U.S. Department of Energy was established, but until last fall the country was just drifting along without a national plan for that disorganized agency to oversee.

President Carter's proposed energy package, consisting of price increases and tax incentives, was sent to Capitol Hill in the spring of 1977. Subsequent haggling over it amounted to nothing less than the moral equivalent of procrastination. And what finally emerged from Congress — a hodgepodge of measures designed to encourage conservation, coal conversion and increased domestic production of oil and gas — did not really satisfy anyone. By then, public opinion polls had begun to report that most Americans either didn't believe the country faced an energy crisis or didn't care. Last year's temporary oil glut did nothing to dispel the growing apathy.

Mineral gluttons?
Despite conservation, U.S. demands will increase.



While action on the political front has been slow, a great deal has been done elsewhere to set the scene for some fundamental shifts in the American life-style. Thanks to technological developments already in the marketplace, it is now possible, says CEQ, "to speak unblushingly of the U.S. becoming a solar society." The tremendous turnout for Sun Day last spring underscored public support for that goal. Conceivably, more than half of all our energy needs could come from solar sources by the year 2020. But solar sources are not the only alternatives being explored. Others include everything from wood chips and seaweed to geothermal energy.

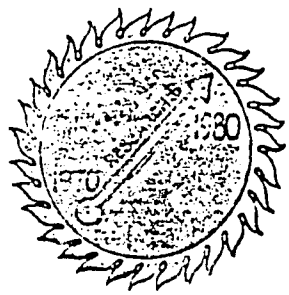
The move away from oil and other conventional energy sources has already begun. Some substitutes are not all that "new." In Maine, for example, nearly half of all homes now rely at least partly on burning wood for heat. In sunny California, on the other hand, state energy regulators say they are committed to solar home heating, giant windmill generators and geothermal steam.

While the so-called "soft" alternatives are looking better and better, nuclear and coal have run into some big problems. Fission, once touted as the wave of the future, has become ensnarled in safety and economic questions. Fusion may be more feasible in the long run, but it will require massive funding for years of research. Coal could dirty up the air and strip mining inflicts costly surface damage. Beyond that, there are serious reservations about coal's long-term effects on the climate.

Unbelievable!
Five years after the oil embargo, there was still no energy plan.

Alternatives are being developed for other minerals as well as for fossil fuels. At the University of Pennsylvania, researchers are working on a "supermetal" made out of ordinary carbon that could replace copper as an electrical conductor. But although the new science of molecular engineering may turn up some valuable substitutes, the most promising idea for conserving raw materials is an old one. It's called recycling.

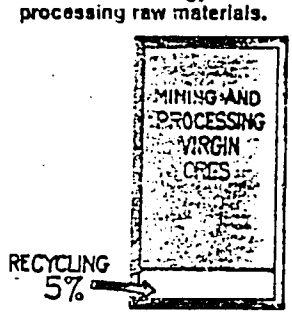
Brave new energy
Technology for solar, wind and other alternatives is developing fast.



Our toughest challenge? In the age of scarcity, making better use of what we have is imperative. That's why recycling can no longer be regarded as just another way to get rid of the trash. It must become nothing less than what one researcher calls "a central organizing principle of the entire economy."

Right now, about two-thirds of all the things we use could be recycled. Americans throw away 70 percent of all metal after it is used just once. Only a fraction as much energy is required to recycle metal as to mine and refine raw ore. And the pollution problems created by the conventional open dump have become unmanageable. The only answer, therefore, is to discard our throwaway mentality and put a new emphasis on waste recovery and material reuse. The know-how exists right now. The resource recovery act was passed in 1976. But until that program is adequately funded, changes will be slow.

The inevitable solution
Recycling will grow, because it takes only 5% as much energy as processing raw materials.

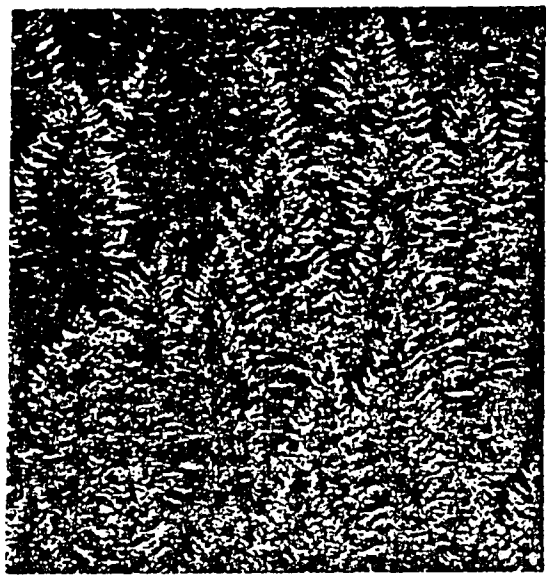


Where to start the transition from conspicuous consumption to thrift and common sense? One good place: peel back all of those old depletion allowances, taxes and shipping rates that penalize recycling and reward all-out exploitation of raw materials. It still costs more to ship scrap than ore.

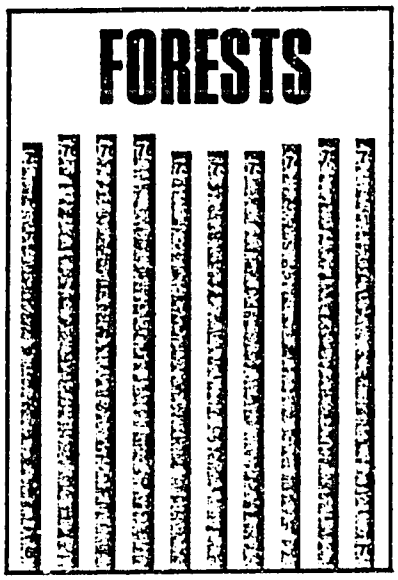
What does this mean to your family? Significant progress can be made without inflicting painful burdens on the American people. But there can be no doubt that adjustments are in store. To economize on fuel, homes and cars will keep on getting more efficient. Mass transportation systems will expand and improve. Utility bills will skyrocket. Electrical appliances will be redesigned for maximum efficiency.

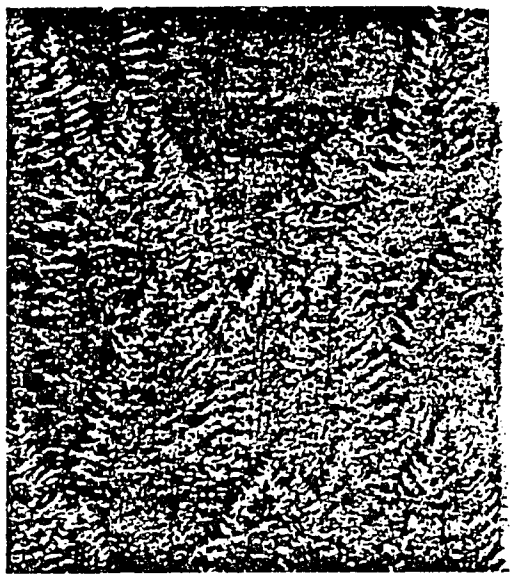
The open dump will become a thing of the past. Families will be separating their trash again (newspapers, cans, bottles) as the first step in comprehensive waste management. Products will be engineered for durability. According to the Worldwatch Institute, energy-wise solutions to some very old problems could range from the substitution of adhesives for nails and bolts to the substitution of telecommunications for mail.

10 year EQ trend



Photograph by Ed Cooper

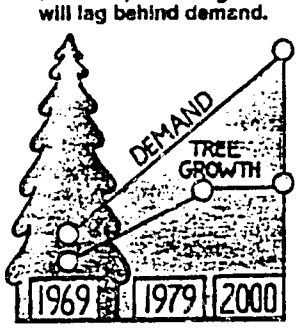




A new era is in sight for our national forests

TEN YEARS AGO, an eight-foot length of two-by-four cost a dollar in Wisconsin, Smokey Bear was 20 years old, and the stage was set for a dramatic redefinition of who and what the nation's forests are for. Old Smokey was familiar to most Americans as the USFS's patron saint of fire prevention, but he and the USFS were troubled by far more than fires. Americans were using more and more wood each year, and the supply was not keeping up with the demand. Result: there was tremendous pressure to increase harvests on 90 million acres of national forests.

The timber crunch
Wood is a renewable resource, but tree growth will lag behind demand.



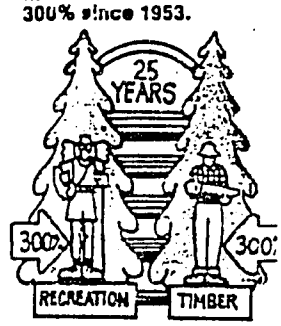
The timber industry was accustomed in 1969 to having its own way in the woods, but there were signs that other forest users would have much more to say in the years ahead. "We must recognize that growing the most timber on the least land in the shortest time does not always contribute to our environmental quality." NATIONAL WILDLIFE insisted in its first EQ Index. "One of the greatest assets of our forests is the role they play in water conservation. They also have important recreational and wildlife values."

Those values were central to many of the conflicts that were brewing over U.S. forests. Increasingly, people were challenging the old practice of clear-cutting — felling every tree in a given area — partly because of its effect on wildlife. There were demands for more ski lifts in national forests, more hunting access, more campsites and hiking trails. Meantime, the old forest problems continued: stream siltation from logging, wasteful harvesting practices, forest pests, destructive fires and, of course, the mounting demand for timber.

Where do we stand today? The original Smokey Bear died in 1976, and that eight-foot two-by-four now costs two dollars. Most of the conflicts over our national forests have still *not* been resolved. But a battery of tough new laws ensures that a better balance will be struck between logging and recreation. Clear-cutting is being closely regulated. Restrictions on logging roads and streamside cutting will produce cleaner waterways and better fishing. It's much tougher to use pesticides in national forests today. And millions of areas of remote forestland, now open to lumbering, may be protected in the future as "wilderness."

Our toughest challenge? It's the same as it was ten years ago: increase wood production to meet booming demands. But the *focus* is shifting away from national forests to small private woodlots and lands owned by the timber companies themselves. Now, hybrid trees and further reduction of wastes in the forest and at the mill will help increase yields on these lands. On public lands, the forest products industry will continue to reap a bountiful harvest, but more consideration will also be given to wildlife, water and recreation.

Something's gotta give!
Recreation and lumbering have both increased 300% since 1953.



What does this mean to your family? You'll pay still more for a two-by-four in the years ahead. But more forestland will be available for you and your children to enjoy. If forest managers receive the funds they're supposed to, you'll see more wildlife on the land. And just maybe the U.S. will be able to have its lumber, and its forests, too!

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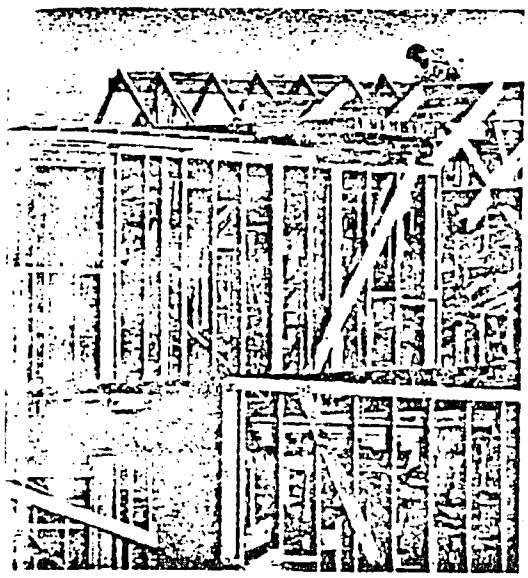
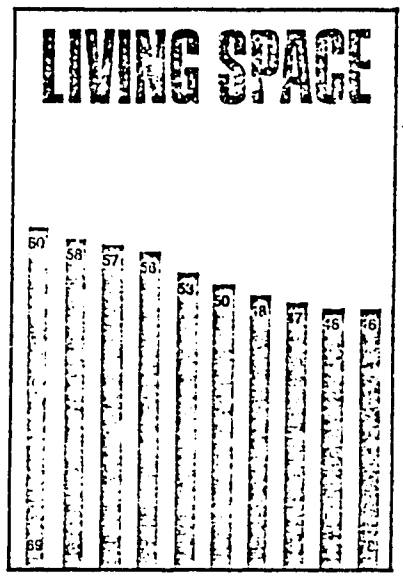
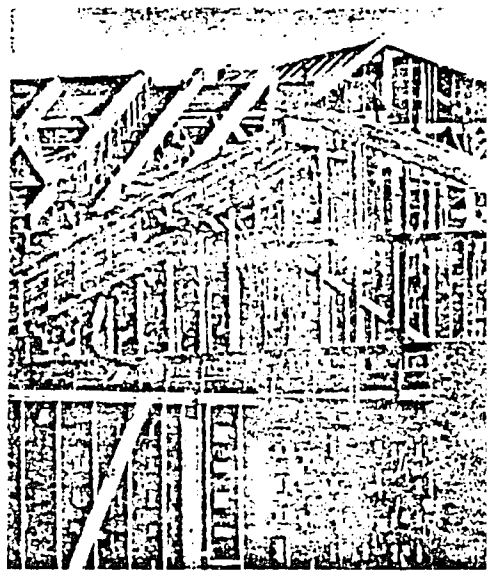
10 year EQ trend







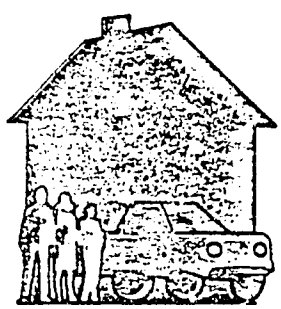
Photograph by Tom Ebenhoh (Black Star)

More people and more demands add up to more problems

TEN YEARS AGO, every big city newspaper was carrying stories about living space problems: the de y of the center cities and suburban sprawl; traffic congestion; noise pollution; and, even such relatively "manageable" problems as garbage disposal and billboard blight. At that time, the public only dimly perceived that the root causes of all living space problems were the population explosion and poor land-use planning.

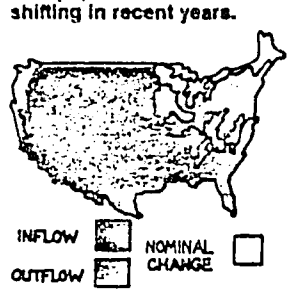
"In the last ten years, we have transformed millions of acres into factories, houses and schools," NATIONAL WILDLIFE noted in its 1970 EQ Index. "Poverty, crime and ghetto tensions are inevitable in a deteriorating environment. People who can afford it are moving to the suburbs. The poor and their problems remain behind — temporarily. In the long run, living space problems will reach everyone. You can't run away. The most urgent need is for wise land-use planning, plus an aroused citizenry to support it."

Resource pressure grows
Today's numerous young families are tomorrow's big consumers.



Where do we stand today? None of the nation's living space problems can in any way be considered "solved," but some important developments have taken place. Six states have developed plans for zoning and managing their fragile coastal areas; another two dozen states are working on similar plans. Highway building is down. Between 1930 and 1960, the total mileage of roads and streets increased nearly four percent each year; since 1970, the increase has slowed to one percent. In our throwaway society, there's even a shortage of space for dumping garbage, though bans on throwaway beverage containers passed by seven states have reduced roadside litter and the volume of solid waste. Although it provides minimal incentive for waste reduction, the Resource Conservation and Recovery Act of 1976 does call for a phaseout of open dumping by 1983, and also for cradle-to-grave regulation of hazardous wastes. Recreation, too, is a function of "living space," and in recognition of this fact, Congress is spending more than $1 billion to expand the nation's trail system, parks and wild rivers.

Westward, Ho . . .
U.S. population has been shifting in recent years.



These gains have been matched by some setbacks in the past decade. National land-use planning legislation has been defeated twice in Congress, and backers probably won't attempt passage again soon. Deterioration of the central cities has increased. Noise pollution has proven to be an unexpectedly expensive and elusive problem.

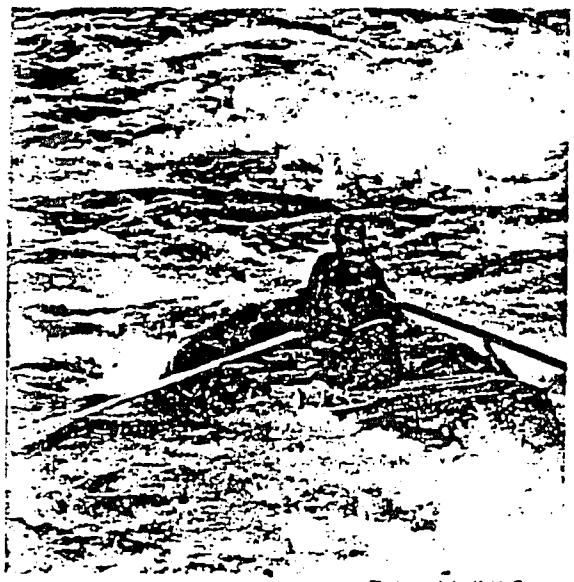
Our toughest challenge? Only nine states have implemented comprehensive land-use plans that require local planning programs. As a result, vast stretches of America's land remain largely unregulated and vulnerable to topsy-turvy development. Passage of state zoning plans is essential to promote wise land use.

What does this mean to your family? One expense item that has risen even faster than the cost of energy is the price a family must pay for a city lot, or a second homesite. As we run out of living space, economic factors will force a more stay-at-home, less consumptive life-style. If you have a vacation home in a woodsy area, count yourself as lucky. If you live in the suburbs now, chances are good that your children will move into rural areas or follow leapfrog development into the exurbs.

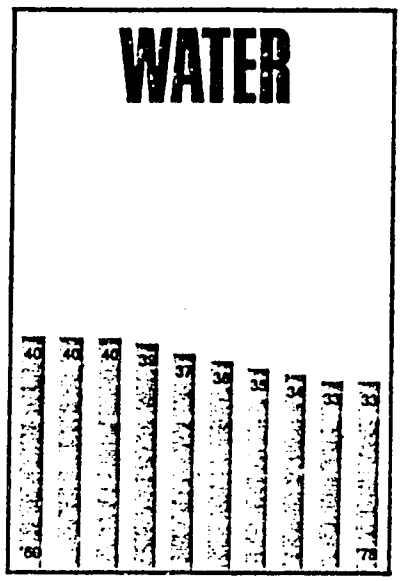
WORSE SAME BETTER

LIVING SPACE · 10 YEARS LATER

10 year EQ trend



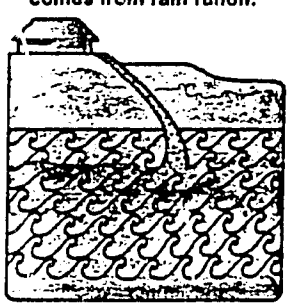
Photograph by Keith Gunnar



How bad is it? Believe it or not, we still don't know

TEN YEARS AGO, the U.S. had just begun to fathom the true depths of its water woes. In some respects, this situation was similar to the dirty-air impasse. Each state was responsible for cleaning up its own mess. Some floated standards so high that they were meaningless. Others dammed up legislation that would at least have prevented things from getting worse. Since Uncle Sam had not yet begun to flog violators, most water pollution just continued to flow along unchecked.

It's uncontrollable!
Half of all water pollution comes from rain runoff.

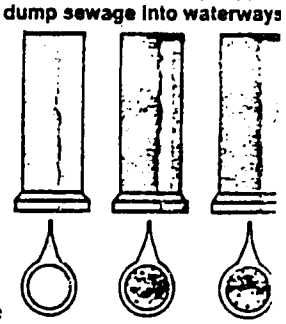


"Water, essential to life, is quickly becoming a conveyor of death," the first NATIONAL WILDLIFE EQ Index reported. "Virtually every stream, river, lake and estuary in the country is polluted. This pollution takes many forms, and because we have too few monitoring devices, the effects of all this on human health are largely unknown."

Industry was considered by far the biggest villain in those days, but more than 2,600 towns and cities were dumping raw sewage directly into lakes and streams, and many other communities were relying on obsolete treatment plants. One measure of that era's naiveté: poisonous rain runoff from sources as diverse as corn fields (pesticides) and city playgrounds (asbestos) was hardly even recognized as a problem.

Where do we stand today? Here, too, the water crisis parallels the nation's air pollution quandaries. Only limited progress has been made despite some heavy action. Federal laws have been passed to make drinking water safe and to control toxic substances. A nationwide water monitoring network is in place. Efforts are underway to improve urban sewage treatment. In 1972, the U.S. gave industry and local governments an ultimatum: stop all direct polluting by 1985. Inevitably, intermediate deadlines were postponed, and too many violators are still doing business as usual.

$19 billion later . . .
Two out of three cities still dump sewage into waterways



There is some evidence that the nation's water *is* getting cleaner. Some 50 water bodies, including the Delaware, Willamette and Susquehanna rivers, have shown considerable improvement. Bacteria and organic waste levels have declined in almost a fourth of the country's 349 drainage basins. About 3,600 of the nation's 4,000 major industrial polluter are meeting their cleanup deadlines, while in many rural areas, DDT and some other pesticide residues are gradually disappearing.

Are these gains deceptive? Many experts think so.

During the past decade, the EPA has given local governments almost $19 billion to build modern sewage-treatment facilities. Even so, two-thirds of all U.S. cities are still dumping partially treated sewage into adjacent waters every day! Several alarming studies say the new sewage plants may be doing little or no good. In Boston, one federal study reports, improvements from an $850 million EPA sewage project will probably range fro "zero to very small." Reason: contamination from rain runoff and other sources won't be affected l the project.

This runoff pollution is called "nonpoint," because it comes from so many differe sources: farms, mines, streets and sidewalk construction sites, erosion and even the wind. Experts now know that nonpoi

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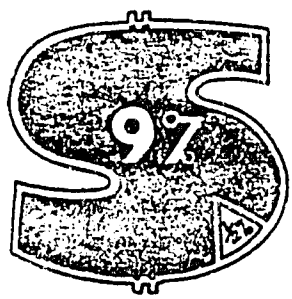
pollution is responsible for more than half of all the nasty compounds entering the nation's waterways. "It's a gigantic problem that we've hardly begun to attack," concedes one EPA official. Even in supposedly pristine Montana, 4,000 miles of streams will not be fishable or swimmable for years because of nonpoint pollution.

The water pollution problem is complicated by an old nemesis: the lack of good monitoring data. Air pollution data, which is highly suspect, is channeled primarily to one federal source for analysis. Water pollution data, also highly suspect, is collected only on a sporadic basis and thus is still incomplete. "We're still in the process of identifying problems," says a CEQ analyst.

What about inflation?

Pollution cleanup adds only ½% to the inflation rate.



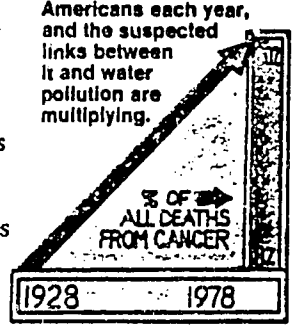
As that process goes on, the dreadful seriousness of water pollution becomes evermore apparent. Recently, scientists discovered that almost half of the lakes above 2,000 feet in New York's Adirondack Mountains have no fish. These lakes have been poisoned in the last 40 years by "acid rain" from airborne pollutants generated in urban areas hundreds of miles away. With no pollution relief in sight, Cornell University researchers are cobbling up a macabre solution: a new variety of "acidproof" brook trout.

Our toughest challenge? It can be summed up in two words: toxic substances. More than 70,000 chemicals are currently being used for commercial purposes in the U.S. Many of them are extremely hazardous. About 1,000 new substances are introduced each year. Some of these poisons are turning up in public water supplies, and this ominous development recently prompted EPA administrator Douglas Costle to tell NATIONAL WILDLIFE: "Perhaps the single most demanding problem we must deal with is the insidious epidemic of poisonous chemicals in our society."

Last summer, residents of the Love Canal district near New York's Niagara Falls abandoned their homes after heavy rains flushed poisonous chemicals into groundwater supplies. Chemicals have been buried in landfills in the area since the 1930s. According to the EPA, Love Canal is only one of some 10,000 landfill sites around the country that have been used to get rid of up to 45 million tons of chemical wastes annually. "There are ticking time bombs all over the place," warns EPA official Steffen Plehn.

The cancer connection

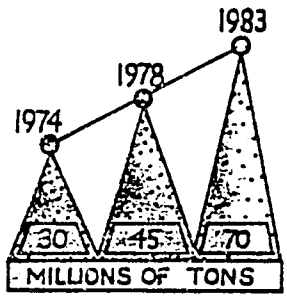
Cancer is killing more Americans each year, and the suspected links between it and water pollution are multiplying.



Many toxic substances get into public water supplies because treatment plants are unable to break them down. Presently, an estimated 50,000 industrial plants flush their wastes right into municipal sewers. Hundreds of others are channeling their wastes into nearby waterways under the EPA's controversial permit program. Many of these permits-to-pollute are now expiring, and the EPA is in the process of doing "a complete overhaul" of the system. The agency has not disclosed what that means.

Ticking time bomb

Hazardous wastes are increasing 10% each year at landfill sites alone.



Last year, the EPA issued new regulations designed to stop contamination of drinking water in cities with more than 75,000 people. These rules require the addition of new filtering devices on treatment systems to remove known cancer-causing chemicals. This may cost local governments up to $800 million in the next five years — an expense that some presidential economic advisors have called "excessively inflationary."

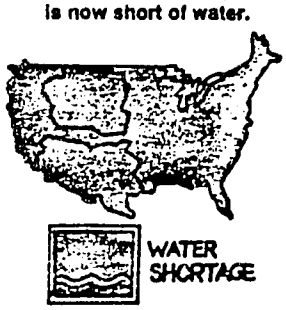
"What is particularly disturbing," a White House inflation study council noted, "is the lack of information about the benefits to be obtained from this regulation." In response to such criticism, EPA's Costle said that his agency would consider changing some cleanup rules if further studies found them to be economically "disruptive."

What does this mean to your family? The EPA's new drinking water regulations may cost each American family an additional $10 to $20 in water bills this year. Overall, water pollution cleanup costs may add up to $100 for each American in 1979. Together with other cleanup programs, they will contribute only about one-half of one percent to the nation's rate of inflation.

Is this price too high? That depends on how much life itself is worth. Many medical researchers are now convinced that environmental factors are a major cause of disease. Cancer, heart and lung diseases, which accounted for 12 percent of the nation's deaths in 1900, cause more than 60 percent of all deaths today. In many cases, it's nearly impossible to say just which "environmental factor" is the culprit.

We need to conserve!

A fourth of the U.S. is now short of water.



If you live in the state of Ohio and your drinking water comes from either Lake Erie or the Ohio River, your chances of dying from cancer are almost ten percent higher than for residents in the middle of the state who get their water elsewhere.

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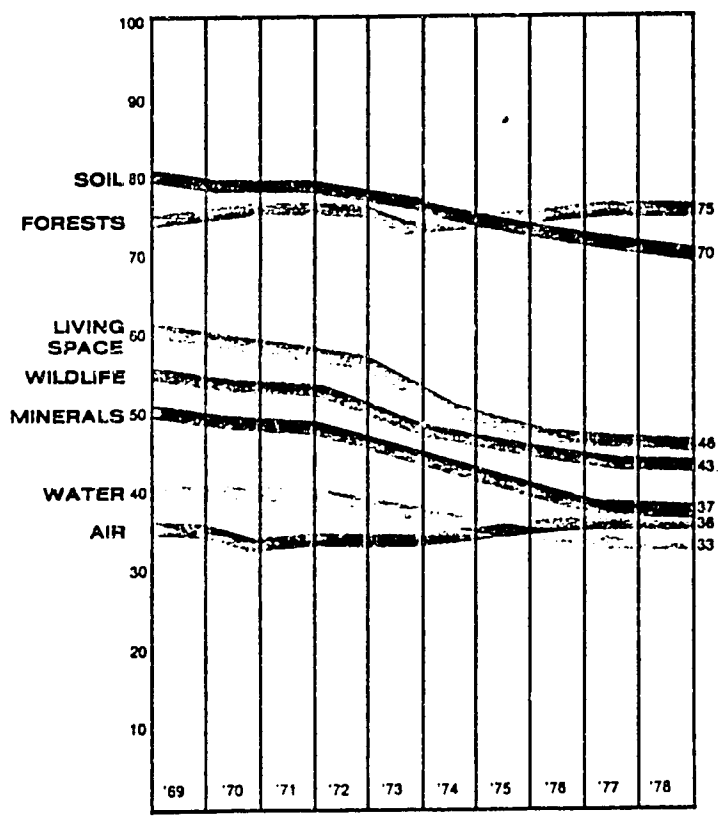
Bald eagle photograph by Michael Gordon



1969-1979 EQ SUMMARY

WILDLIFE: DOWN

Though widespread habitat loss continues, important new laws and conservation programs have been established.

AIR: UP

Prodded by tough federal standards, air polluters have slowly cleaned up their act. But, in many areas, air is still not safe to breathe.

SOIL: DOWN

In the face of rampant soil erosion and urban sprawl, prime farmland has declined while the nation's food needs have grown.

MINERALS: DOWN

As the U.S. plodded toward a national energy and conservation policy, the days of cheap fuel and abundant minerals vanished forever.

FORESTS: SAME

A battery of tough forestry laws ushered in a new era of timber management, offering hope that the U.S. can avoid wood shortages.

LIVING SPACE: DOWN

Without effective land-use planning, vast stretches of America's land have remained vulnerable to topsy-turvy development.

WATER: DOWN

As cleanup efforts got underway, the complexities of the country's water pollution problems became more apparent.

How the EQ Index is put together

NATIONAL WILDLIFE's annual Environmental Quality Index is a subjective analysis of the state of the nation's natural resources. The judgments on resource trends represent the collective thinking of editors and the National Wildlife Federation staff, based on consultation with government experts, private specialists and academic researchers.

Source: Environmental Reviews at the Community Level-
A Program Guide,
U. S. Dept. of Housing and Urban Development,
October, 1975

FORMAT I

ENVIRONMENTAL REVIEW RECORD
(24 CFR 58.11)

A. APPLICANT:

CHIEF EXECUTIVE OFFICER:

B. PROJECT DATA:

See: 24 CFR 58.11(a)

C. EXISTING ENVIRONMENTAL CONDITIONS
AND TRENDS:

See: 24 CFR 58.15(a)

D. RELEVANT A-95 MATTERS:

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E. COMPARISON WITH APPLICABLE STANDARDS AND PLANS: The project has been compared with applicable standards and plans, with the following results:

	PROJECT IS		
	IN COMPLIANCE		NOT APPLICABLE
FACTOR:	**YES**	**NO**	
(1) Local Comprehensive Plans, including Land Use and Growth Management elements			
(2) Areawide (or Regional) Plan			
(3) Local Zoning Ordinances			

FACTOR:	**RATING**	**SOURCE/ DOCUMENTATION**
(4) Noise Standards		
(5) Flood Plain Standards		
(6) Coastal Zone Standards		
(7) Wetlands Standards		
(8) Air Quality Standards		
(9) Water Quality Standards		
(10) Wildlife Standards		
(11) Other Standards (specify)		

See: 24 CFR 58.5(c)
24 CFR 58.15(b)

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F. SITE-STRUCTURE-DESIGN SUITABILITY: PHYSICAL FACTORS. (Matters Affecting the Project) The project has been examined with reference to the effect on the project of each of the factors indicated below, with the following results:

FACTOR:	RATING	SOURCE/ DOCUMENTATION
(1) Slope Stability		
(2) Foundation Conditions		
(3) Terrain		
(4) Soil Permeability		
(5) Ground Water		
(6) Natural Hazards		
(7) Man-Made Hazards		
(8) Nuisances		
(9) Compatability in use and scale with environment		
(10) Neighborhood Character		

See: 24 CFR 58.5(c)
24 CFR 58.15(b)

G. SITE-STRUCTURE-DESIGN SUITABILITY: SERVICE DELIVERY FACTORS. (Matters Affecting the Project) The project has been examined with reference to the effect on the project of each of the factors listed below, both as such factors now exist and as they are programmed to exist, with the following results:

FACTOR:	RATING		SOURCE/ DOCUMENTATION
	EXISTING	PROGRAMMED	
(1) Elementary Schools			
(2) Junior and Senior High Schools			
(3) Employment			
(4) Shopping			
(5) Park, Playground and Open Space			
(6) Police and Fire			
(7) Health Care and Social Services			
(8) Transportation			
(9) Water Supply System			
(10) Sanitary Sewer System			
(11) Other Services (specify)			
(12) Storm Sewer System			
(13) Solid Waste Disposal			
(14) Other Utilities (specify)			
(15) Paved Access to Site			
(16) Radio and TV Reception			

See: 24 CFR 58.5(c)
24 CFR 58.15(b)

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H. IMPACTS ON SURROUNDING ENVIRONMENT: PHYSICAL FACTORS. (Matters Affected by the Project The project has been examined with respect to each of the factors listed below, with reference to whether or not the project will have any effect on the surrounding environment, with the following results:

FACTOR:	RATING	SOURCE/ DOCUMENTATION
(1) Impact on unique geological features or resources		
(2) Impact on rock and soil stability		
(3) Impact on soil erodability		
(4) Impact on ground water (level, flow, quality)		
(5) Impact on open streams and lakes		
(6) Impact on plant and animal life		
(7) Impact on energy resources		
(8) Impact on aesthetics and urban design		

See: 24 CFR 58.5(c)(d)
24 CFR 58.15(b)

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I. IMPACTS ON SURROUNDING ENVIRONMENT: SERVICE DELIVERY FACTORS. (Matters Affected by the Project) The project has been examined with respect to each of the factors listed below, both as such factors now exist and as they are programmed to exist, with reference to whether or not the project will have any effect on the surrounding environment, with the following results:

FACTOR:	RATING		SOURCE/ DOCUMENTATION
	EXISTING	PROGRAMMED	
(1) Elementary Schools			
(2) Junior and Senior High Schools			
(3) Employment			
(4) Shopping			
(5) Park, Playground and Open Space			
(6) Police and Fire			
(7) Health Care and Social Services			
(8) Transportation			
(9) Other Services (specify)			
(10) Water Supply System			
(11) Sanitary Sewer System			
(12) Storm Sewer System			
(13) Solid Waste Disposal			
(14) Other Utilities (specify)			
(15) Paved Access to Site			
(16) Radio and TV Reception			

See: 24 CFR 58.5(c)(d)
24 CFR 58.15(b)

J. IMPACTS ON SURROUNDING ENVIRONMENTAL: SPECIAL FACTORS: (Matters Affected by the Project) The project has been examined with respect to each of the special factors listed below, with reference to the effect of the project on such special factors, with the following results:

FACTOR:	AFFECTED BY PROJECT		NOT APPLICABLE
	* YES	** NO	
(1) Historic Properties			

*Carry out and document procedures set forth at 36 CFR Part 800

**Document this conclusion

FACTOR:	RATING	SOURCE/ DOCUMENTATION
(2) Individuals and Families: (a) Displaced (b) Emplaced (3) Impact on Social Fabric and Community Structures (4) Other Special Factors (specify)		

See: 24 CFR 58.5(c)(d)
24 CFR 58.15(b)

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K. ENVIRONMENTAL IMPACTS IDENTIFIED. The following environmental impacts (beneficial and adverse) have been identified with respect to the project:

See: 24 CFR 58.5(c)(d)
24 CFR 58.15(b)

L. TREATMENT OF ENVIRONMENTAL IMPACTS. Changes which can be made in order to eliminate or minimize adverse environmental impacts and to enhance environmental quality are:

(1) The project itself can be modified, as follows:

(2) Factors external to the project itself can be modified, as follows:

See: 24 CFR 58.5(d)
24 CFR 58.15(c)(1)

M. ALTERNATIVES TO THE PROJECT. Alternatives to the project which have been considered, and the results of such consideration, are as follows:

See: 24 CFR 58.5(d)
24 CFR 58.15(c)(2)

N. CONDITIONS AND SAFEGUARDS. If this project is undertaken, the following conditions and safeguards should be implemented in order to protect or enhance environmental quality, or minimize adverse environmental impacts.

See: 24 CFR 58.5(a)

O. LEVEL OF CLEARANCE FINDING. Based upon the foregoing environmental assessment, it is concluded that:

(1) **FINDING**: A request to HUD for release of funds for the within project **is not an action significantly affecting the quality of the human environment**, and no EIS is required.

The reasons supporting the above finding are:

CLEARANCE PROCEDURES:

( ) **Notice of Finding of No Significant Effect on the Environment** has been published and disseminated and a true copy of same is attached hereto as Exhibit _____.

( ) **Public Hearings were not held.**

( ) **Public Hearings** respecting the subject of this environmental review were held at the following dates, times and places.

See: 24 CFR 58.15(d)(1)
24 CFR 58.16

(2) **FINDING**: A request to HUD for release of funds for the within project **is an action significantly affecting the quality of the human environment**, and an EIS is required.

CLEARANCE PROCEDURES:

( ) Notice of Intent to File EIS has been published and disseminated and a true copy of same is attached hereto as Exhibit _____.

( ) **Public Hearings** were not held.

( ) **Public Hearings** respecting the subject of this environmental review were held at the following dates, times and places:

( ) **Notice of Public Hearing** prior to preparation and dissemination of the Draft EIS was published and a true copy thereof is attached hereto as Exhibit _____.

( ) **Notice of Public Hearing** on the Draft EIS, after preparation and dissemination of the Draft EIS, was published and a true copy thereof is attached hereto as Exhibit _____.

( ) **Draft EIS** and **Summary Sheet** were prepared and disseminated as required and:

( ) **Notice** of same was published by CEQ in the Federal Register on (date); and

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( ) **Review Period for Draft EIS** (45 days, plus any extensions granted) expired on (date).

( ) **Final EIS** was prepared and disseminated and submitted to CEQ, as required, on (date); and

( ) Review Period for Final EIS expired on (date).

See: 24 CFR 58.15(d)(2)
24 CFR 58.17

P. CERTIFICATION AND RELEASE OF FUNDS.
( ) A period of 90 days has expired since the date of publication in the Federal Register of the filing of the Draft EIS; and ( ) a period of 30 days has expired since the Final EIS was submitted to CEQ; and this project is eligible for certification and release of funds.

( ) 5-Day Notice was published on (date) specifying that a request for release of funds and Certification would be submitted to HUD on (date); a true copy of the notice is attached as Exhibit _____.

( ) Request for Release of Funds was submitted to HUD on (date) and a copy of same is attached hereto as Exhibit _____.

( ) Certification was submitted to HUD on (date) and a copy of same is attached hereto as Exhibit _____.

( ) Approval by HUD of the Certification and Request for Release of Funds (Notice of Release of Grant Conditions) was received on (date).

See: 24 CFR 58.1
24 CFR 58.5
24 CFR 58.30
24 CFR 58.32

Q. ADDITIONAL INFORMATION

See: 24 CFR 58.19
24 CFR 58.27
24 CFR 58.31

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INSTRUCTIONS

FORMAT I

The Environmental Review Record (ERR) constitutes the written record of the applicant's performance of the environmental review process pertaining to a particular project or group of related projects. It may be prepared in accordance with the foregoing form, which is HUD-approved and should contain sufficient substance to provide a supportive administrative record establishing the fact that the applicant has carried out all NEPA responsibilities for review, decisionmaking and action respecting the project in compliance with 24 CFR 58. The format is intended to serve as a model toward building such a record and the following explanations are intended to serve as guidelines to assist the applicant.

Rating environmental factors. Items E-J on the format suggest that certain of the indicated factors be rated. Based upon the best available information, supplemented as necessary, each environmental factor should be rated in a manner such as the following:

A – The factor is acceptable. There are no special problems associated with this factor. Adverse impacts are negligible; other effects are neutral or beneficial.

B – The factor is questionable. Problems associated with this factor call for discretion in granting environmental approval to the project. Ameliorative measures should be pursued and may be mandated by specific environmental or program policies. Conditions and safeguards (Item N.) may be a prerequisite for approval.

C – The factor is undesirable or unacceptable. Problems associated with this factor are serious and rejection may be mandated by specific environmental or program policies. Ameliorative measures should be vigorously pursued. Approval should be allowed only upon specific conditions and safeguards (Item N.) and then only when justified by a careful examination and comparison of alternatives.

N.A. – The factor is not applicable to this project. For example, access to local schools is not applicable to an elderly housing project; coastal zone environmental policies do not apply to inland projects; etc.

Use of Ratings. The use of the symbols "A", "B", "C" and "N.A." in the format is not intended to suggest that such symbols be used by the applicant. The symbols are used in the format for convenience in illustrating the environmental review process. In carrying out that process, the applicant should analyze each applicable environmental factor and that analysis should be stated in the ERR. The above symbols and their representative text, together with the references to "rating" in the format, are intended only to suggest a manner in which such analysis might be set forth in the ERR.

Consideration of Impacts. The above ratings and most of the illustrative issues set forth in these instructions are principally directed toward identifying and measuring *adverse* impacts. However, it is emphasized that "adversity" is only one aspect of inquiry in the environmental review process. Any alteration of existing environmental conditions, or creation of a new set of environmental conditions, *adverse or beneficial*, caused or induced in whole or in part, directly or indirectly, by the proposed project of the applicant, constitutes an "environmental impact." All such impacts should be identified and a determination made as to their *significance* (i.e., their potential consequence). Assessment of the significance of an environmental impact generally involves two major elements: (i) a quantitative measure of magnitude, and (ii) a qualitative measure of importance. It is the *significance* of the environmental impact of a proposed project which, under NEPA, determines whether or not and EIS must be prepared. "Adversity" of the impact is relevant in determining such significance, as well as the separate determination of whether or not to proceed with a proposed project.

Source/Documentation. Items E-J on the form call for Source/Documentation respecting certain factors and the ratings given. The ERR, including all supporting evidence, constitutes the administrative record of the performance of the environmental review process. In the column designated "Source/Documentation," refer to specific attachments, or to specific portions of the project file, specific documents or other records or data. The acronym "FO" (Field Observation) may be used where observations made during field inspection form the basis for the indicated rating. In such cases, the person making the observations and the dates should be identified. Documentation may include studies or portions of studies conducted by others, written explanations and clarifications by the reviewer based on field visits, conversations with experts, maps, or other information used as the basis of the rating and conclusions on the form. Where material is of a nature that cannot be attached or inserted in the ERR, it should be referenced on the form.

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Item A.

The name, address, zip code and phone number of both the applicant and the chief executive officer of the applicant should be stated.

Item B.

Briefly describe the project covered by this ERR. The description should include mention of each separate activity included in the project—i.e., acquisition, demolition, removal, construction, relocation, etc.—and should indicate costs, location, time factors, etc. The description must be adequate to enable the reader to envisage the general nature, magnitude and extent of the project. If such project description exists in another format (i.e., a proposal, plan, etc.) it may be inserted, or attached to the ERR as an exhibit, or otherwise incorporated in the ERR. In such cases, a reference to the project description should be set forth here.

Item C.

Generally describe the environment of the project site and the surrounding area as it exists without the project—i.e., presently. Identify pertinent physical factors, such as land uses, soil, climate, noise, air, water, vegetation, etc. Indicate the nature and extent, or the absence of, service delivery systems and facilities, the social and economic character, population densities, etc. Environmental trends (i.e., movement toward new or different environmental conditions) should also be identified and described. This item is very important, in that it will serve as the data base from which future change will be measured.

Item D.

If clearinghouse or other agency comments or other matters arising out of the OMB Circular A-95 process respecting this project were considered as part of the environmental review, or are otherwise relevant to it, document that fact here.

Item E.

Describe the results of having compared the project to applicable standards and plans. The description should be sufficient to indicate (i) any actual violations of law; (ii) whether or not the project is incompatible with an establishe plan, or fails to meet an established standard. Where incompatability with an established plan exists, an analysis and determination of whether or not to proceed with the project should be recorded and a decision to proceed should be explained. Projects which are unlawful should be rejected. The following environmental statutes, policies and regulations are applicable. (Numbers correspond to designation on form.)

(4)● HUD Handbook 1390.2, Noise Abatement and Control, Departmental Policy, Responsibilities and Standards, 1971.

(5)● Flood Disaster Protection Act of 1973 (PL 93-234) and implementing regulations.

● Title 24, Chapter X, Subchapter B, National Flood Insurance Program.

● Executive Order 11296.

(6), (7)● Coastal Zone Management Act of 1972 (PL 92-583). Also, any applicable State legislation or regulations.

(8)● Clean Air Act (PL 90-148)

● Clean Air Act Amendments of 1970 (PL 91-604)

● Applicable U.S. Environmental Protection Agency (EPA) implementing regulations, including State implementing plans and regulations, especially those pursuant to:

● 40 CFR 15, Administration of the Clean Air Act With Respect to Federal Contracts, Grants or loans;

● 40 CFR 50, National Primary and Secondary Ambient Air Quality Standards;

● 40 CFR 51, Requirements for Preparation, Adoption and Submittal of Implementation Plans; and

● 40 CFR 52, Approval and Promulgation of Implementation Plans.

(9)● Federal Water Pollution Control Act (PL 92-500)

● Applicable U.S. Environmental Protection Agency (EPA) implementing regulations.

(10)● Fish and Wildlife Coordination Act (PL 85-624)

Item F.

Describe the results of having examined the project with reference to the effect upon it of each of the factors listed on the form. If one or more of the listed factors will affect the project, the extent or

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potential extent of such effect should be determined and indicated. If it cannot be determined whether or not a listed factor will affect the project, the reasons for not being able to make such determination should be explained. This analysis is designed to determine if the site and surrounding area represents a suitable environment for the project, especially if residents may be involved. To assist in clarifying the meaning of terms used on the form, the following is a list of representative issues. (Numbers correspond to designation on form.)

(1) Will the project be subject to hazardous landslides, falling rock, or other unstable slope conditions due to site or surrounding topographic or geologic conditions?

(2) Can excessive deformations of foundations occur because of changes in moisture content, soil swelling or shrinkage, frost action on soils, liquefaction, substantial soil loss from construction practices, water or wind erosion, inadequate weight bearing capacity, or subsidence due to sink hole, mine excavation or water withdrawal?

(3) Is the site subject to unusual terrain features such as steep slopes, abutting rock formations, or other conditions affecting construction, drainage, or livability? Does the proposed development appear to take advantage of the natural features of the site and area?

(4) Will impermeable layers such as clay affect construction drainage, or water infiltration required to replenish ground water supplies? Will impermeable layers result in ground water contamination due to septic tank or well development?

(5) Is the site subject to rapid water withdrawal problems which change the depth or character of the water table, affect water supply, septic tank or vegetation?

(6) Are there unusual risks from natural hazards such as geologic faults, flash floods, volcanic activity, mudslides or fires, or from the presence of ponds, or hazardous terrain features?

(7) Are there unwarranted risks from man-made hazards such as inadequate separation of pedestrian and vehicluar traffic, roadway design or lack of traffic control, visual obstructions to traffic, improper use of materials, or presence of hazardous materials such uranium mill tailings, or liquid petroleum storage areas, or the presence of potentially hazardous industrial activity or material in the surrounding area?

(8) Is the site subject to nuisances from odors, vibrations, unslightly areas, nearby landfills, inconveniences or other nuisances?

(9) Is the project compatible with the surrounding area in terms of land use density, scale, mass, texture and architectural design?

(10) Is the project site in an area of physical deterioration, or physical investment? Is it in an area of transition in terms of density or types of land use? Is the development taking place or anticipated in the area compatible with the project?

Item G.

Describe the results of having examined the project with reference to the effect upon it of each of the factors listed on the form. Both existing services and programmed services (i.e., those scheduled to commence at or about a date certain in the future) should be taken into account. Services should be rated both in terms of *access to* the service and *adequacy of* the service. If one or more of the listed factors will affect the project, the extent or potential extent of such effect should be determined and indicated. This portion of the ERR should be sufficient to indicate whether or not the existing and/or programmed services applicable to the proposed project, both in terms of *access* and of *adequacy*, are or will be suitable to serve it. To assist in clarifying the meaning of terms used on the form, the following is a list of representative issues. (Numbers correspond to designation on form.)

(1) Does the project location provide for adequate and safe access to school for elementary school age children? Are the quality and capacity of such schools adequate?

(2) Does the project location provide adequate and safe access to school for junior and high school age children? Are the quality and capacity of such schools adequate?

(3) Is there adequate access to employment opportunities for proposed occupants? Is there an adequate supply of employment opportunities considering the skill and income requirement of potential proposed occupants?

(4) Is there adequate and convenient access to shopping?

(5) Is there adequate and convenient access to parks, playgrounds and functional open space areas?

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Are the parks, playgrounds and open space facilities in the project and surrounding area adequate to meet the needs of proposed occupants?

(6) Does the project location allow for adequate access for police and fire protection services?

Are the police and fire protection service available to the project adequate to meet the project needs?

(7) Is there adequate access to hospitals, emergency facilities, clinics and doctors services?

Are medical services adequate to meet the needs of the residents?

Does the location provide convenient access to social services offered by the community such as day care, youth services and special assistance to the aged if required by the proposed occupants?

Are the social services offered adequate to meet special needs of the residents?

(8) Do proposed occupants have convenient access to community transportation services? Is transit accessible for proposed occupants dependent on such services?

Are the transportation services serving the project adequate to meet the project needs in terms of destinations, schedules, transfer requirements and costs?

Are roads and off-street parking facilities adequate for private transportation?

(9) (10) Will the water supply and sanitary sewer systems be adequate to serve the proposed project and its occupants?

Will they meet fire flow, State health and any special treatment requirements?

Will water usage affect the water table or cause infiltration or subsidence?

(11) Identify and rate other services not listed, which may be applicable. (i.e., Telephone, where adequacy of existing facilities is an issue)

(12) (13) Will the storm sewer and solid disposal utilities be adequate?

(14) Identify and rate other utilities not listed (i.e., telephone service).

(15) Is there paved access to the site sufficient for convenient ingress and egress and to allow and encourage services into the site?

(16) Is radio and T.V. reception via airwave, cable, etc. adequate and not subject to interference?

Item H.

Describe the results of having examined the project with reference to the effect of the project upon the surrounding environment, in terms of each of the factors listed on the form. If the project will affect or potentially affect the surrounding environment, the extent or potential extent of such effect should be determined and indicated. This portion of the ERR should be sufficient to indicate whether or not the project may result in any physical alteration of the environment surrounding the project site and the extent of any such effect. To assist in clarifying the meaning of terms used in the form, the following is a list of representative issues. (Numbers correspond to designation on form.)

(1) Will the project location, construction or activities of project residents substantially impact unique geologic features on or near the site?

(2) Will the project have an adverse impact on rock and soil stability due to weight of buildings on surficial materials, liquifaction or water infiltration into surrounding soils from man-made impoundments, or transport route construction?

(3) Will the project make the area substantially more susceptible to erosion because of grading, increased runoff, inadequate vegetive cover during or after construction, inadequate drainage plain or other causes?

(4) Will the project impede natural drainage patterns, which cannot be corrected, cause alterations in stream channel form, or otherwise affect groundwater movement?

Will construction over recharge areas substantially affect aquifer yields or water quality?

Will erosion or increased weathering rate of bedrock result in groundwater contamination?

(5) Will erosion, increased runoff, or wastes from the project contaminate open streams and lakes? Will disruptions of water flow affect

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the characteristics of open streams and lakes?

(6) Are there unique species of plant or animal life particularly susceptible to adverse impact from construction and human habitation?

Is there vegetation present, the loss of which would deny habitat to unique wildlife species, or to a substantial number of different animals? Will such vegetation be preserved?

Will plant or animal life be adversely affected by disruptions to the nutrient cycle or hydrologic balance?

(7) Are community energy supplies adequate to accommodate the energy consumption in the project? Are there indications that the project will promote inefficient energy utilization?

(8) Will the project adversely affect the aesthetic image of the surrounding area? Will the project block views? Is the proposed design integrated with the area in which it is located?

Item I.

Describe the results of having examined the project with reference to the effect of the project upon the surrounding environment, in terms of each of the factors listed on the form. Both existing services and programmed services should be taken into account in this examination and any effect the project will have should be determined and indicated. This portion of the ERR should be sufficient to indicate whether or not the project will overload or otherwise unreasonably or undesirably burden the service delivery systems which exist or are programmed to deliver services to the environment surrounding the proposed project. The items designated (1) - (16) on the form should each be examined in terms of issues such as the following:

- Is the capacity of the listed item adequate to accommodate additional utilization which will result from the project?
- Will the availability or quality of the service from the listed item suffer as a result of usage arising from the project?
- Will the project cause the listed item's utilization rate to be pushed close to capacity?
- Will the project interfere with existing public access to other areas or services?

See instructions for Item G, for additional specialized probes.

Item J.

Describe the results of having examined the project with reference to the effect of the project on the surrounding environment, in terms of any special factors, other than physical or service delivery factors. Special factors which must be addressed are listed on the form, but there may be others. Any factor which, because of its unique or specialized character, might have the potential of pointing up serious environmental concerns, should be addressed. This portion of the ERR should be sufficient to indicate that the applicant has taken into account any such special factors which arise out of or are affected by the project and has carried out any required procedures necessary to deal with such factors. The following comments and representative issues are to assist in clarifying the terms used on the form. (Numbers correspond to designation on form.)

(1) Self explanatory. It is important that the conclusion that a historic property will not be affected by the project be carefully documented. The following policies and regulations are applicable:

- National Historic Preservation Act of 1966 (Pub. L 89-665);
- Preservation of Historic and Archeological Data Act of 1974 (Pub. L. 93-291) and regulations which may be issued thereunder;
- Executive Order 11593, Protection and Enhancement of the Cultural Environment, 1971;
- Procedures for Protection of Historic and Cultural Properties, Advisory Council on Historic Preservation, 36 CFR Part 800.

(2) Will the project force the displacement of individuals and families?

Is the project calculated to result in the emplacement of individuals and families?

Will the project destroy or relocate existing jobs, facilities, services or business enterprises, or create or attract any of the same, so as to indirectly result in the immigration or emigration of individuals and families?

Is there an adequate relocation plan, or has

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potential immigration or emigration been taken into account?

(3) Will the project substantially change the income, racial, ethnic or age distribution of the neighborhood or community, or the institutions serving those population groups?

Have the implications and probable consequences of such changes been taken into account?

(4) Identify and rate any special factors, not listed, which might be affected by the project.

Item K.

Identify and describe each alteration of existing environmental conditions, adverse or beneficial, which will be caused or induced, in whole or in part, directly or indirectly, by the proposed project. The description should be sufficient to enable the reader to generally determine the nature, magnitude and extent of each identified impact.

Item L.

Determine and discuss changes which can be made in such things as proposed plans, policies, schedules, designs, locations, etc. in order to eliminate or minimize any adverse environmental impacts and to enhance environmental quality. In the treatment of adverse impacts, the prospects of changing things which are not part of the project should be explored, as well as changes to the project itself. For example: Locating a proposed housing project adjacent to a heavily traveled roadway could result in adverse impacts in the form of noise, dust, pollution, etc. To treat such adverse impacts, the project itself might be modified by changing its site to a location more removed from the roadway. However, such adverse impacts might also be eliminated or minimized by changing things other than the project, such as relocating the roadway, improving the paving, constructing a barrier, reducing the traffic by redirection, etc.

Item M.

Determine and describe possible alternatives to the proposed project, including the alternative of no project. Discuss whether or not identified impacts can be eliminated or minimized, or environmental quality enhanced, through adoption of such alternatives. The feasibility of each alternative and the reasons why each should be adopted or rejected should be discussed sufficient to indicate an adequate consideration thereof.

Item N.

Determine and describe all conditions or safeguards which should be implemented in order to protect or enhance environmental quality, or minimize or eliminate adverse environmental impacts, if the project is undertaken. For example: The housing project mentioned at Item L., above, should perhaps not be undertaken unless either the project site is changed, or the roadway is relocated, etc. In such case, such site change or roadway change would be a condition or safeguard which should be herein stated and implemented, if the project is undertaken.

Item O.

Based upon the environmental assessment of the project, (Items B. - N.) conclude whether or not the request for release of funds for the project will constitute an action significantly affecting the quality of the human environment. State the reasons in support of any negative finding. After making the level of clearance finding, carry out the Clearance Procedures in accordance with that finding and complete the form as indicated.

Item P.

Complete the form as indicated.

Item Q.

Record additional information, as appropriate, such as additional public hearings, special problems, litigation, objections to Certification, "lead agency" responsibilities, the written decision mentioned at 24 CFR 58.19 (c) and other matters not covered specifically in the format. Attach or refer to pertinent documents or records.

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Environmental Index

The Environment Index, 1981, Environment Information Center, Inc.,
292 Madison Avenue, N. Y., 10017

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UNITED STATES INTERNATIONAL ENVIRONMENTAL REFERRAL CENTER

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of the

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International Referral System for Sources of Environmental Information
UNEP/INFOTERRA

Office of Management and Agency Services
Assistant Administrator for Planning & Management
U.S. Environmental Protection Agency
Washington, D.C. 20460

The United Nations Environment Program (UNEP) was created in 1972 as a direct result of the International Conference on Human Environment held in Stockholm, Sweden. UNEP is an independent agency of the United Nations with headquarters in Nairobi, Kenya. Its establishment evolved around three goals:

1. To promote international cooperation in the environmental field.

2. To keep under review the world environmental situation in order to assure that environmental problems of wide international significance receive appropriate consideration by governments.

3. To promote the acquisition, assessment and exchange of environmental knowledge.

In order to assist in carrying out these goals, several programs were created within the UNEP structure, one of which was the International Referral System (UNEP/IRS). In January 1979 this referral system was renamed INFOTERRA, an acronym that will be used by all four of the U.N. languages. Composed of a network of over 80 national and sectoral Focal Points, INFOTERRA is engaged in identifying and registering sources of environmental information, transmitting these sources in a unified format to the System's central data bank in Geneva, Switzerland, and serving as a point of contact for users who need referral services (national and international). INFOTERRA is a referral service designed to link those who need environmental information with those who have the desired information.

In March 1975 the State Department designated the U.S. Environmental Protection Agency to serve as the U.S. National Focal Point and EPA formally opened the Center on October 6, 1975, at its Headquarters in Washington, D.C. The U.S. National Focal Point has been named the United States International Environmental Referral Center (USIERC).

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ATOMIC INDUSTRIAL FORUM
7101 Wisconsin Ave.
Washington, DC 20014

EPIA (Electric Power Industry Abstracts): data base covers from August 1975 to the present. Contains 21,000 citations on environmental impact statements and studies by electric utilities and regulatory agencies that relate to licensing and operation of nuclear and fossil-fueled power plants. Specific topics include radioactive wastes, air and water pollution, nuclear fuel processing, and nuclear safeguards. Provides hard copy retrieval and online terminal access (through SDC). Contact: Carl Walske, (301) 654-9260.

BUREAU OF NATIONAL AFFAIRS, INC.
1231 25th Street, NW
Washington, DC 20037

CHEMLAW: data base contains fully indexed text of all currently in-force and adopted federal chemical regulations. Available online (through NIH-EPA Chemical Information System and DIALOG). Contact: Charlotte A. Kuenen, (202) 454-4554.

CAMBRIDGE SCIENTIFIC ABSTRACTS
5161 River Road
Washington, DC 20016

POLLUTION ABSTRACTS: data base covers from January 1970 to the present. Contains 65,000 literature citations on international special reports, conference proceedings, technical and nontechnical periodicals, and books in the areas of solid wastes, marine resources, toxic substances, and air, freshwater, marine, radiological, noise, and land pollution. Available in journal form (*Pollution Abstracts* and *Ocean Abstracts*), annual cumulative indexes, microfilm, magnetic tapes, and online (through Lockheed Dialog). Licensing by special arrangement; lease price $4,000/yr for 1982. (inquire for backfiles) Contact Avril Howells, (301) 951-1403. For editorial information contact Pam Eilers, (301) 951-1404.

EIC—ENVIRONMENT INFORMATION CENTER, INC.
48 West 38th St.
New York, NY 10018

ENVIROLINE: data base covers from January 1971 to the present. Contains 75,000 citations on international special reports, conference proceedings, technical and nontechnical periodicals, books, congressional hearings and reports, speeches, and films in the areas of air, water, radiological, and noise pollution, chemical contamination, energy and nonrenewable resources, education, urban ecology and land use, food, population, international issues, oceans and estuaries, renewable terrestrial and aquatic resources, solid wastes, transportation, weather modification, and wildlife. Available in monthly journal form (*Environment Abstracts*), an annual cumulative index (*Environment Index*), special publications (*Land Use Planning Abstracts* and *Toxic Substances Sourcebook*), hard copy and microfiche retrieval, magnetic tapes, and online (through Dialog, SDC, and BRS); price information available on request. Contact: Sarah Noll, (212) 944-8500.

ENVIRONMENTAL PROTECTION AGENCY
Office of Library Systems & Services
401 M St., SW
Washington, DC 20460

EPA LIBRARY SYSTEM: data base 1973 to the present. Contains 1.7 million citations on special report, journal, and book holdings in EPA libraries. Is composed of seven separate machine-readable files: Air Ecology, EPA Reports, International Environmental, Journal Holdings, Hardbound Book, Circulation, and Document Control. Air Ecology contains citations on literature dealing with air pollutants and their effects on flora and fauna; International Environmental has citations covering major international literature on the environment and life sciences. Information assistance to the public includes library services; data base is not commercially available. Contact: Carol Alexander, (202) 755-0353.

INFORMATION RESOURCES PRESS, INC.
1700 N. Moore St.
Arlington, VA 22209

EIS (Environmental Impact Statements): data base covers from January 1977 to the present. Contains 10,000 citations on all the environmental impact statements submitted to EPA. Available in monthly journal form (*EIS: Digest of Environmental Impact Statements*), an annual cumulative index, hard copy and microform retrieval, magnetic tapes, and online (through BRS). Lease price available from BRS. Contact: Jean Allen, (703) 558-8270.

U.S. DEPT. OF AGRICULTURE
Technical Information System
Nat'l Agriculture Library Bldg.
Beltsville, MD 20705

AGRICOLA (AGRI-Cultural On-Line Access): data base covers from January 1970 to the present. Contains 1.5 million citations primarily on journal articles in the areas of forestry, nutrition, pesticides and fertilizers, and soil conservation. Available in hard copy retrieval and online (through SDC, Lockheed, and BRS). Contact: Phil Turner, (301) 344-3813.

CRIS (Current Research Information Service): data base covers from January 1969 to the present. Contains 27,000 citations describing the current research programs of USDA and state agricultural experiment stations in the areas of agriculture, agricultural engineering, chemistry and chemical engineering, and general science and technology. Data base is not commercially available. Contact: John R. Myers, (301) 344-3846.

U.S. DEPT. OF COMMERCE
Nat'l Oceanic & Atmospheric Admin. (NOAA)
3300 Whitehaven St., NW
Washington, DC 20234

ESIC (Environmental Science Information Center): data base covers from January 1970 to the present. Contains 150,000 citations on the works of agency research scientists and technical service offices in the areas of climatology, marine and freshwater pollution, toxic substances, and coastal zone management. Available in library services and online (through Lockheed and ESIC). Contact: Bob Walter, (301) 443-8330.

U.S. DEPT. OF COMMERCE
Nat'l Technical Information Service (NTIS)
5285 Port Royal Rd.
Springfield, VA 22161

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NTIS BIBLIOGRAPHIC DATA FILE: data base covers from July 1964 to the present. Contains 650,000 citations on technical reports generated by U.S. and foreign government-sponsored research: its environmental coverage deals with air, water, radiological, noise, and land pollution, toxic substances, and solid wastes. Available in weekly newsletters in 26 subject areas (including Environmental Pollution & Control, Natural Resources & Earth Sciences, Transportation, and Urban & Regional Technology & Development), a biweekly government reports announcement, published searches, hard copy and microfiche retrieval, and magnetic tapes (through several online commercial vendors or through a lease from NTIS); lease price, $4,000/yr. Contact: David Grooms, (703) 557-4808.

U.S. DEPT. OF HEALTH & HUMAN SERVICES
Nat'l Library of Medicine
8600 Rockville Pike
Bethesda, MD 20014

TOXLINE (Toxicological Information Online): data base covers from 1974 to the present. Contains 692,000 citations on research articles that deal with the effects of pollutants and toxic agents on human health in the environment and the workplace. Available in print form (*Toxicity Bibliography* and *Pesticide Abstracts*), hard copy, microfiche retrieval, and online (through Nat'l Library of Medicine). Contact: Melvin Spann, (301) 496-1131.

U.S. DEPT. OF INTERIOR
Water Resources Scientific Information Center (WRSIC)
18th & C Sts., NW
Washington, DC 20140

WRSIC: data base covers from 1969 to the present. Contains 100,000 citations on government-sponsored research reports in the areas of water resources, water pollution, and hydroelectric applications. Available in bimonthly journal form *(Selected Water Resources Abstracts)* and online (at some of the nation's water resources research institutes). Contact: Raymond A. Jensen, (202) 243-6097

Source: Environmental Impact Assessment - A Bibliography with Abstracts, 1980, Brian D. Clark, Ronald Bisset, Peter Wathern, R. R. Bowker Company, N. Y.. N. Y.

Selected periodicals

Introduction

Articles on environmental impact assessment (EIA) have appeared in a wide range of periodicals. No attempt has been made to list all periodicals mentioned in this bibliography. Instead, details of a small number of selected publications are included. These periodicals are of two types. Some which appear at short intervals, for example, weekly or monthly, often contain topical articles on trends and events in EIA. Other periodicals which are issued over longer time spans, for example, bimonthly or quarterly contain articles reviewing particular aspects of EIA or presenting the results of studies carried out in EIA. It is recommended that both types of periodicals are scanned regularly by those interested in EIA.

Built Environment. London: Kogan Page, 1937, quarterly.

Civil Engineering, American Society of Civil Engineers. New York: American Society of Civil Engineers, 1930, monthly.

Ecology Law Quarterly. Berkeley: University of California School of Law, 1971, quarterly.

EIA Review. Cambridge, Massachusetts: Laboratory of Architecture and Planning, Massachusetts Institute of Technology, 1978, irregularly.

Environment. St. Louis, Missouri: Scientists' Institute for Public Information, 1958, ten issues per year.

Environment Reporter. Washington, D.C.: Bureau of National Affairs Incorporated, 1970, monthly.

Environmental Affairs. Boston, Massachusetts, Environmental Law Center, Boston College Law School, 1971, quarterly.

Environmental Comment. Washington, D.C.: Urban Land Institute, 1973, monthly.

Environmental Impact News. Westport, Connecticut: Technomic Publishing Company Ltd., 1975, monthly.

Environmental Law Reporter. Washington, D.C.: Environmental Law Institute, 1971, monthly.

International Environment Reporter. Washington, D.C.: Bureau of National Affairs, 1978, monthly.

International Journal of Environmental Studies. London: Gordon and Breach Science Publishers Ltd., 1970, quarterly.

Journal of the American Institute of Planners. Washington, D.C.: American Institute of Planners, 1925, bimonthly. *

Journal of Environmental Management. London: Academic Press, 1973, bimonthly.

Natural Resources Journal. Albuquerque, New Mexico: University of New Mexico School of Law, 1961, quarterly.

Natural Resources Lawyer. Chicago: American Bar Association, 1968, quarterly.

New Scientist. London: New Science Publications, 1956, weekly.

Plan Canada. Ottawa: Canadian Institute of Planners, three issues per year.

Proceedings of the American Society of Civil Engineers, Journal of the Environmental Engineering Division. New York: American Society of Civil Engineers, 1956, bimonthly.

Proceedings of the American Society of Civil Engineers, Journal of the Hydraulics Division. New York: American Society of Civil Engineers, 1956, bimonthly.

*Now Journal of the American Planning Association

Proceedings of the American Society of Civil Engineers, Journal of the Irrigation and Drainage Division. New York: American Society of Civil Engineers, 1956, quarterly.

Proceedings of the American Society of Civil Engineers, Journal of the Professional Activities Division. New York: American Society of Civil Engineers, 1956, quarterly.

Proceedings of the American Society of Civil Engineers, Journal of the Transportation Engineering Division. New York: American Society of Civil Engineers, 1956, quarterly.

Proceedings of the American Society of Civil Engineers, Journal of the Urban Planning and Development Division. New York: American Society of Civil Engineers, 1956, quarterly.

Proceedings of the American Society of Civil Engineers, Journal of the Waterways, Ports, Coastal and Ocean Engineering Division. New York: American Society of Civil Engineers, 1956, quarterly.

Science. Washington, D.C.: American Association for the Advancement of Science, 1880, weekly.

Social Impact Assessment Newsletter. New York: C. P. Wolf (ed.) Environmental Psychology Program, City University of New York, 1976, monthly.

Weekly Government Abstracts. Environmental Pollution and Control. Springfield, Virginia: National Technical Information Service, US Department of Commerce, weekly.

Source: Sourcebook on the Environment - A Guide to the Literature, 1978, Edited by Kenneth A. Hammond, George Macinko, Wilma B. Fairchild, The University of Chicago Press, Chicago, Ill.

Appendix C: Selected List of Environmental Organizations

Daniel P. Beard

A wide variety of organizations, both public and private, have an interest in environmental affairs. This appendix presents a sample of organizations that may be of assistance to anyone doing research on environmental topics. The list is divided into several categories: (1) comprehensive directories and sources of environmental information; (2) international, national, and interstate organizations that could provide research assistance; (3) federal agencies, departments, and offices dealing with environmental affairs; and (4) congressional committees with jurisdiction over environmental legislation.

Directories and Environmental-Information Sources

Conservation Directory 1977. Washington, D.C.: National Wildlife Federation. 1977. c. 220 pp.

A comprehensive and descriptive list of organizations, agencies, and officials concerned with natural resource use and management. This directory is the most comprehensive available and is updated yearly.

Directory of Consumer Protection and Environmental Agencies. Edited by Thaddeus C. Trzyna (and others). Orange, N.J.: Academic Media, 1973. 627 pp.

A comprehensive descriptive listing of national and state, public and private, agencies and organizations concerned with consumer and environmental protection. Includes indexes of organizations, personnel, publications, and subjects.

Directory of Environmental Information Sources. Edited by Charles E. Thibeau. (2d ed.) Boston: National Foundation for Environmental Control, Inc.; Cahners Books, 1972. 457 pp.

A descriptive listing of selected national and local agencies and organizations, trade associations, and bibliographies. Contains useful, but somewhat dated, listings of federal agency publications.

Directory of Information Resources in Agriculture and Biology. Beltsville, Md.: National Agricultural Library/U.S. Department of Agriculture, 1972.

A companion volume to the National Referral Center directories (see below).

Directory of Information Sources in the United States. Compiled by the National Referral Center, Library of Congress. Washington, D.C.: U.S. Government Printing Office.

This item comprises a series of specialized directories that include the following areas:

Biological Sciences, 577 pp , 1972.
Federal Government, 416 pp., 1974. (Describes services and information provided by agencies.)
General Toxicology, 293 pp., 1969.
Physical Sciences, Engineering, 803 pp., 1971.
Water, 243 pp., 1966.

Directory of Pollution Control Officials. In *The Environment Index 74*, pp. 34–48. New York Environment Information Center, Inc., December 1974.

The annual *Environment Index* also contains summaries of environmental legislation, conferences, events, patents, books, and films.

Environment U.S.A.: A Guide to Agencies, People, and Resources. Compiled and edited by the Onyx Group, Inc. Glenn L. Paulson, advisory editor (and others). New York: Bowker, 1974. 451 pp.

A useful book containing extensive descriptions of environmental agencies and organizations; directories of consultants, corporate officials, environmental education programs, libraries, conferences, films, and news organizations; plus subject bibliographies and chapters on selected public-interest issues.

Environmental Information Sources Handbook. Edited by Garwood R. Wolff. New York: Simon and Schuster, 1974. 568 pp.

Addresses, brief descriptions of organizations, principal publications and other services provided, and the name of a contact are found in this reference. The work is indexed under nine separate headings, such as "Curriculum Guides and Sources," "Periodicals," and "Libraries," in addition to being indexed alphabetically by organization and subject.

Guide to EPA Libraries. Washington, D.C.: U.S. Environmental Protection Agency, Library Systems Branch, Office of Planning and Management, May 1973. 44 pp.

This publication (FPA-LIB-73-02) describes the holdings of the Agency's headquarters, regional, and national research centers, and libraries in various cities.

Information Resources in the Environmental Sciences. Edited by George S. Bonn. (Papers Presented at the 18th Allerton Park Institute, 12–15 November 1972.) Champaign-Urbana: University of Illinois, Graduate School of Library Science, 1973. 238 pp.

These conference proceedings contain discussions of the full range of environmental-information sources. Useful appendices provide listings of federal government environmental activities, information centers, and publications, as well as of environmental libraries and journals.

New Information Services in Social Problem Areas: Energy, Environment and Transportation. Compiled by James E. Freeman, James P. Kottenstette, and Martin D. Robbins. Denver: University of Denver, Industrial Economics Division, Denver Research Institute, 1973. 86 pp.

Presents bibliographies of new serials since 1962 in the fields of energy, environment, and transportation, with comments on the kind of publishing going on in these fields.

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State and Local Environmental Libraries: A Directory. Washington, D.C.: U.S. Environmental Protection Agency, Library Systems Branch, July 1973. 24 pp.

Contains listings of libraries with environmental holdings. Arranged by states.

United States Government Manual, 1974–75. Washington, D.C.: Office of the Federal Register, National Archives and Records Service, General Services Administration, 1974; available from the U.S. Government Printing Office. 799 pp.

This basic reference, formerly known as the *Government Organization Manual*, contains descriptions of government environmental programs and gives the availability of major agency publications.

Yell-O Pages. Washington, D.C.: Environmental Resources, Inc., 1971. 224 pp.

This directory (organized by states) is primarily for the use of those interested in local environmental groups, but listings of national environmental organizations and publications are also included.

International, National, and Interstate Organizations

Letters following the entries indicate the form of the organizations' publications: J (journal); N (newsletter); P (public-information pamphlets or other materials).

Air Pollution Control Association, 4400 Fifth Ave., Pittsburgh, Pa. 15213 (412–621–1090). J.

American Association for the Advancement of Science, 1515 Massachusetts Ave., N.W., Washington, D.C. 20005 (202–467–4400). J.

American Chemical Society, 1155 16th St., N.W., Washington, D.C. 20036 (202–872–4600). J, P.

American Forestry Association, 1319 18th St., N.W., Washington, D.C. 20036 (202–467–5810). J.

American Geographical Society, Broadway at 156th St., New York, N.Y. 10032 (212–234–8100). J, N.

American Institute of Biological Sciences, Inc., 1401 Wilson Blvd., Arlington, Va. 22209 (703–527–6776). J.

American Petroleum Institute, 1801 K St., N.W., Washington, D.C. 20006 (202–833–5600). J, N, P.

Association of American Geographers, 1710 16th St., N.W., Washington, D.C. 20009 (202–234–1450). J, N, P.

Center for Natural Areas, 1525 New Hampshire Ave., N.W., Washington, D.C. 20036 (202–265–0066). N.

Center for Science in the Public Interest, 1779 Church St., N.W., Washington, D.C. 20036 (202–332–6000). N, P.

Chamber of Commerce of the United States, 1615 H St., N.W., Washington, D.C. 20006 (202–659–6174). P.

Concern, Inc., 2233 Wisconsin Ave., N.W., Washington, D.C. 20007 (2[illegible] 965–0066). P.

Conservation Foundation, 1717 Massachusetts Ave., N.W., Washington, D.C. 20036 (202–265–8882). N.

Defenders of Wildlife, 2000 N St., N.W., Washington, D.C. 20036 (202-223-1993). N.

Environmental Action, Inc., Room 731, 1346 Connecticut Ave., N.W., Washington, D.C. 20036 (202-833-1845). J.

Environmental Policy Center, 324 C St., S.E., Washington, D.C. 20003 (202-547-6500).

Friends of the Earth, 620 C St., S.E., Washington, D.C. 20003 (202-543-4312). J.

Fund for Animals, Inc., 140 W. 57th St., New York, N.Y. 10019 (212-246-2096). N.

International Association of Game, Fish and Conservation Commissioners, 1412 16th St., N.W., Washington, D.C. 20036 (202-232-1652). N. P.

Izaak Walton League of America, 1800 North Kent St., Suite 806, Arlington, Va. 22209 (703-528-1818). J.

League of Conservation Voters, 324 C St., S.E., Washington, D.C. 20003 (202-547-7200). P.

National Audubon Society, 950 Third Ave., New York, N.Y. 10022 (212-832-3200). J, P.

National Parks and Conservation Association, 1701 18th St., N.W., Washington, D.C. 20009 (202-265-2717). J.

National Recreation and Park Association, 1601 N. Kent St., Arlington, Va. 22209 (703-525-0606). J, P.

National Wildlife Federation, 1412 16th St., N.W., Washington, D.C. 20036 (202-483-1550). J, N, P.

Nature Conservancy, Suite 800, 1800 N. Kent St., Arlington, Va. 22209 (703-841-5300). J, P.

Planned Parenthood Federation of America, 810 Seventh Ave., New York, N.Y. 10019 (212-541-7800). F.

Population Reference Bureau, 1755 Massachusetts Ave., N.W., Washington, D.C. 20036 (202-232-2288). J, N, P.

Public Interest Research Group, 2000 P St., N.W., Suite 711, Washington, D.C. 20036 (202-833-9700). N. P.

Resources for the Future, Inc., 1755 Massachusetts Ave., N.W., Washington, D.C. 20036 (202-462-4400). N, P.

Scientists' Institute for Public Information, 30 E. 68th St., New York, N.Y. 10021 (212-249-3200). N, P.

Sierra Club, 1050 Mills Tower, San Francisco, Cal. 94104 (415-981-8634). J, N, P.

United Nations Environment Programme, P.O. Box 30552, Nairobi, Kenya. New York Liaison Office, P.O. Box 20, Grand Central Station, New York, N.Y. 10017. J.

Water Pollution Control Federation, 3900 Wisconsin Ave., N.W., Washington, D.C. 20016 (202-362-4100). J.

Wilderness Society, 1901 Pennsylvania Ave., N.W., Washington, D.C. 20006 (202-293-2732). J.

Wildlife Management Institute, 709 Wire Bldg., Washington, D.C. 20005 (202-347-1774). J, N.

Wildlife Society, Suite S-176, 3900 Wisconsin Ave., N.W., Washington, D.C. 20016 (202-363-2435). J.

Zero Population Growth, Inc., 1346 Connecticut Ave., N.W., Washington, D.C. 20036 (202-785-0100). N.

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II. GENERAL

SOURCE: "Soil Erosion and the Role of Agricultural Language on Potential Erosion in Sierra Leone"
Ph.D. Dissertation
Boham, Andrew K., April 24, 1980

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The Quest for Harmony: Perspectives on the New International Development Strategy. By Calestous Juma. A Report of the Environment Liaison Centre, Nairobi, Kenya, August 1980, 63 pp. Registers dissatisfaction of non-governmental organizations with development strategies of past 20 years and proposes environmentally sound alternatives.

Renewable Bio-solar and Microbial Systems in "Eco-rural" Development. By E. J. DaSilva. In, Impact of Science on Society, v. 30(3) July-September 1980, pp. 225-236. Adequate low-cost energy supplies can be created from earthworms, biofertilizers, and biofuels.

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Traditional Technology, A Neglected Component of Appropriate Technology: Characteristics and Problems—A Malaysian Case Study. By Khor Kok Peng. A Working paper for United Nations University, HSDRSTT-4/UNUP-250. 1980, 27 pp. Exchange of traditional local technology between villages and between countries can be an important part of development where appropriate. Includes general remarks in addition to Malaysian case study.

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T R No 1	Land in Sierra Leone: a reconnaissance survey and evaluation for agriculture, based on the work of C J Birchall and P Bleeker, in collaboration with C Cusani-Visconti. FAO Freetown, 1979. AG:DP/SIL/73/002 T R 1.
T R No 2	Vegetation and Land Use in Sierra Leone: a reconnaissance survey, based on the work of O L A Gordon, G Kater and D C Schwaar. FAO Freetown, 1979. AG:DP/SIL/73/002 T R 2.
T R No 3	Proceedings of the first national remote sensing seminar on land resources (Freetown, 24 - 29 April 1978), based on the work of management and staff of LRSP Project in collaboration with the Remote Sensing Unit of FAO/Hqs. FAO Freetown, 1979. AG:DP/SIL/73/002 T R 3.
T R No 4	Review of remote sensing techniques for multi-disciplinary land evaluation purpose. (A case study on the practical applications of high flight aerial photography in Sierra Leone), based on the work of D C Schwaar. FAO Freetown, 1979. AG:DP/SIL/73/002 T R 4.
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T D No 3	A Framework for Land Suitability Classification with particular reference to Sierra Leone, by P Bleeker 1976.
T D No 4	Guidelines for the Transfer of Details from HFAP onto small scale Topo Base Map by means of optical pantograph, by D C Schwaar 1976.
T D No 5	A Preliminary Framework for Soil Classification and Correlation in Sierra Leone, by C J Birchall 1976 (draft).
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T D No 7	Summary of Sierra Leone Agriculture Trade Statistics 1963/1976, by W K Alkire & P Bleeker 1977.
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T D No 9	Notes for Participants in Senior Staff Seminar in Photo-Interpretation for Land Resources Survey (10 to 21/10/77), by C J Birchall and G Kater 1977.
T D No 10	Notes for the In-Service Training of Soil Survey Officers and Field Assistants, by C J Birchall and T N J Lamboi 1977.
T D No 11	Review and Selection of Remote Sensing Imagery for Integrated Land Resources Surveys, by D C Schwaar 1978.
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T D No 14	High Flight Aerial Photography for Reconnaissance Land Evaluation, by C J Birchall 1978.
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T D No 17	Basic Principles of Photo-Interpretation and Orientation of Aerial Photographs, by O L A Gordon 1978.
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T D No 28	Proposals for Future Development and Improvement of Management Level and Farming System (Seminar paper) by C Cusani-Visconti 1979.

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Misc No 16	Report on Duty Tour of the LRSP Co-Manager to WARDA, Liberia (4 - 9/3/79), by M S Kargbo 1979.
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