INDIA RESOURCES MANAGEMENT ANALYSES AND TECHNOLOGIES

Final Report
Project Concept Review

Contract No.
386-0249-C-00-9272-00

Submitted to:
USAID/INDIA

Submitted by:
CHEMONICS INTERNATIONAL CONSULTING DIVISION

CHEMONICS
2000 M. St., N.W. Suite 200
Washington, D.C. 20036
Phone (202) 466-5340
Fax (202) 331-8202
Telex 440361 CHNC UI

February 28, 1990

TABLE OF CONTENTS

		Page
Summary		i
Introduction		1
SECTION I	INDIA'S NATURAL RESOURCE PROBLEMS	3
	A. Nature and Scope of the Problems	3
	1. Biomass Resources	3
	2. Soil Resources	6
	3. Water Resources	7
	B. USAID's Approach	8
	C. AID Program Setting	9
	D. The RMAT Project Setting	10
SECTION II	THE RMAT PROGRAM SETTING	13
	A. The Natural Resource Information Problem	13
	B. Organizational Problems in Natural Resource Management Information	14
	1. Data Collection	14
	2. Data Dissemination	15
	3. Data Analysis	16
SECTION III	RMAT PROJECT OPPORTUNITIES	17
	A. The Natural and Human Resource Problem Focus	18
	1. Biomass Resource Problems and Project Activities	18
	a. Forest Biomass Monitoring and Assessment Activity	18
	b. Farm-Based Biomass Inventory and Monitoring Activity	21
	c. Biomass Processing and Marketing Activity	22
	d. Natural Resource Information Dissemination	23

TABLE OF CONTENTS
(continued)

			Page
	2.	Soil Resource Problems and Activities	24
		a. Farm-Based Soil Conservation Activities	25
		b. Catchment Area Management Activities	25
		c. Information Technologies for Soil Conservation Site Selection	26
	3.	Water Resource Management Problems and Activities	27
		a. Decision-Support Systems for Improved Micro-system Design and Management	27
		b. Decision-Support Systems for Improved Macro-system Design and Management	28
		c. Data and Information for Micro- and Macro-system Decision Support	29
	4.	Human Resource Problems and Activities	31
		a. Inventory and Dissemination of Current Practices and Community Dynamics	32
		b. Interdisciplinary Training for Water Engineers	33
		c. Technical Training for Environmental NGOs and PVOs	34
		d. Professional Society Support	34
B.	Technical Opportunities and Issues		35
	1.	Productivity Tools	36
	2.	Data Acquisition Systems	36
		a. Automated Instrumentation	37
		b. Remote Sensing	37
	3.	Database Management Systems	38
		a. General Purpose Systems	38
		b. Special Purpose Systems	38
		c. Issues	38

TABLE OF CONTENTS
(continued)

		Page
	4. Geographic Information Systems	39
	a. Issues	39
	5. Systems Analysis Models	40
	6. Expert Systems	40
	7. Mass Storage System	41
C.	Organizational Strengths and Opportunities	41
	1. Interested in, and Appropriate for, RMAT	42
	a. Private Organizations	42
	b. Governmental Organizations	44
	2. RMAT Role Yet to Be Determined	46
SECTION IV	RMAT ACTIVITY PRIORITIES AND PHASING	49
TABLE 1.	Agencies, Technologies, and Activities	51
TABLE 2.	Logframe	52
References		55

SUMMARY

India's economy is heavily dependent on its natural resources. While there is a plethora of data regarding these resources, there is a surprising lack of reliable information on the nature, scope, and serious situation of the resource base. Current and future private and public investments (Indian and foreign) are at risk in India.

Renewable natural resources perform services beyond production of food, fiber, fuel, and income such as recycling of nutrients, detoxification of noxious chemicals, purification of waters, and regulation of hydrological processes. However, even in the United States with its vast array of natural resource information systems at state and national levels and intense public debate on natural resource issues, market signals are not always the best indicators of the scarcity and importance of resources, especially when considering long-term impacts.

India is severly hampered by lack of essential information on basic questions of water, soil, and biomass stocks and utilization trends. Consequently, resource allocations and policy decisions are made without adequate information with catastrophic results: water use efficiency is less than 40 percent of optimum (U.S. standards are on the order of 60-90 percent); 13 million hectares of irrigated land (over 16 percent of total irrigated land) suffer from water-related problems; energy imports per unit of merchandise exported has doubled in real-cost terms in the last 20 years; the useful life for reservoirs has been overestimated by a factor of three due to siltation problems; and ineffective and inadequate controls on industrial processesing result in heavy pollution and environmental catastrophes (e.g., the Bhopal disaster).

While Indian natural resource agencies have a long record of collecting and archiving vast amounts of <u>data</u>, their record of acquiring, analyzing, and disseminating <u>useful management information</u> is less exemplary. Indeed, it is essential to comprehend the difference between collected data and useful management information.

Management information is derived from a prior specification of the issues to be addressed by the decision process. Without prior specification of the particular natural resource problems to be addressed, data collection is not only purposeless, but wasteful of scarce staff time and financial resources. Not only are natural resource decisions thereby assured of being inefficient, but the costs are borne twice in that otherwise useful financial and staff resources are squandered. Few countries can afford this; India clearly cannot. Proper information is

essential to the efficient management of existing natural resource investments and to the formulation of an efficient strategy for new investments.

The Resources Management Analyses and Technologies (RMAT) project proposes the increased use of computer equipment, computer software, and skilled managers and entrepreneurs to improve the acquisition, analysis, and dissemination of natural resource information in India. The specific problems that RMAT will focus on are: (1) the assessment and monitoring of biomass, (2) the development of improved soil erosion controls, (3) the improved economic efficiency of water resource management and related investments, and (4) the strengthening of human skills in natural resource management.

The U.S. experience with natural resource information systems provides a solid basis to assist the Indian economy. Management information systems have flourished over the past two decades making better decisions possible. Equally important, policy reforms such as the requirement for environmental impact statements have empowered millions of citizens formerly denied access to information on which major federal actions were formulated and justified. The RMAT project can assist to open up the bureaucracy and empower millions of Indians to participate in natural resource decisions and policies.

The RMAT project combines U.S. capabilities in natural resource information systems with the emerging computer-oriented private sector in India to address serious natural resource scarcity and depletion. The project will focus on biomass assessment and monitoring, reducing soil erosion, and improving the economic efficiency of water resource decision making. The project will accomplish several goals: (1) the core of economic growth will not be jeopardized by natural resource scarcity; (2) biological diversity will be enhanced; (3) natural resource agencies will save money by rationalizing their data acquisition, analysis, and dissemination activities; and (4) the fledgling Indian computer industry (both hardware and software) will be bolstered. The RMAT project will draw on existing human resource skills in India, particularly those found in environmentally oriented NGOs, to improve natural resource management in India. It can also to serve as a catalyst for similar changes in the Asian region.

AID's emerging mandate includes support for open markets, pluralism, and more efficient and sustainable public institutions. A cost-effective way to provide this support is through timely assistance in reforming management information systems. Such information systems: (1) lower transaction costs and so facilitate market mechanisms; (2) inhibit policy distortions and perverse incentives; (3) facilitate institutional capabilities to manage the use of natural resources while sustaining local

environments; (4) provide improved analytical and information bases so that appropriate policies can be developed; and (5) increase popular participation in natural resource decision making, which is so critical to India's sustained economic growth.

AID's concern for intellectual property rights is also pertinent to RMAT. Intellectual property rights are of interest to those who create or transfer knowledge that has a private market value. In the area of natural resource management, the economic value of information is inversely related to its hoarding and control. Improved natural resource management is a collective (or public) good, quite unlike the private-good character of an invention, or a new software program. There is no coherent economic argument to support the hoarding of information for natural resource management precisely because there is no market for that information that gives rise to appropriable economic benefits to the party in control of such information. Indeed, AID's goals of "open markets and open societies" can be met if, and only if, natural resource management information is available--at very low cost--to all parties with an interest in a particular natural resource management decision. The idea of pluralism without low-cost client-oriented public information is a contradiction in terms.

INTRODUCTION

Chemonics International Consulting Division was contracted by USAID/India to conduct a brief review of the Resources Management Analyses and Technology (RMAT) project concept. The scope of work required Chemonics to present its findings on the technical feasibility of the concept and to identify and present an initial outline of a design for:

- the problems the project will address;
- the potential sites for project activities;
- the proposed Indian participants in project activities; and
- the organizations from which the project would work.

The mission had recently conducted a number of evaluations of ongoing projects and developed a Country Development Strategy Statement and Agricultural Sector Strategy. The RMAT project concept evolved from this process. USAID/India plans to use the preliminary design proposals in this document to augment other project development work that was conducted in 1989. This work will form the basis for the team to be fielded in subsequent months to develop a Project Identification Document.

This review was undertaken during a period of transition in current AID strategies for programming development assistance. The strategies under revision include the environmental and natural resources areas that are addressed in this project concept. The review team did obtain a briefing from AID/Washington in early January that highlighted some of the strategies in transition. However, the team was not structured to address these new strategies directly.

As set out in the scope of work, Chemonics fielded an interdisciplinary four-person team in January 1990 for approximately three weeks:

Team Leader/Resource Economist	Dr. Daniel Bromley
Water Resources Management Specialist	Dr. David Ford
Land Use/GIS Specialist	Dr. Charles Hutchinson
Applied Economic Anthropologist	Dr. David Guillet

The first draft of the report was presented to the mission on January 22 and 23, 1990. Comments received during those briefings were incorporated into this final draft. Other comments from the mission were received on February 23, 1990 and were also considered in finalizing this report.

The team wishes to thank USAID/India for its support in carrying out the work. We hope that this report is useful to the mission as it moves into the more detailed phases of project development.

Previous Page Blank

SECTION I

INDIA'S NATURAL RESOURCE PROBLEMS

A. Nature and Scope of the Problems

India remains one of the world's poorest countries, with a per capita income approximating $350 per year. The current minimum wage, Rs 21 per day (approximately $1.25 in early 1990), is not uniformly observed, particularly for women. Official estimates place 40 percent of the population below the modest poverty level. Yet India is rapidly evolving into a modern economy with an advanced--though often stifled--industrial sector, and with a large and highly educated, skilled work force in many technologically sophisticated sectors. However, the most elemental resources that supply these advancing sectors are poorly managed, act as a major constraint to future growth, and threaten to undermine the core of the economy.

Many of the rural masses are hampered in their attempts to enter the growing economic sectors from which the urban middle classes are increasingly benefiting. The disparity in such benefits across sectors in India can be seen by comparing the average annual growth rates in gross domestic product since 1980. Between 1980 and 1987, Indian industry averaged annual growth rates of 7.2 percent, the service sector averaged annual growth rates of 6.1 percent, while agriculture--in which the overwhelming majority of Indians are engaged-- experienced annual growth rates of only 0.8 percent (World Bank 1989). Failure to improve the management of India's natural resources, on which agriculture is inevitably based, not only relegates three quarters of the population to continued misery, but threatens the very growth in industry and services that have been the best performers since 1980. We now examine some of the underlying natural resource problems.

1. Biomass Resources

The depletion of biomass in India is a serious problem. Families in parts of the Deccan Plateau have only one cooked meal per day because of the shortage of fuelwood, and in many parts of India women and children spend an average of 5-6 hours per day in search of cooking fuel such as twigs, dung, and agricultural residues. In economic terms, this allocation of time means that they are not able to undertake other necessary tasks. Soil fertility suffers from the absence of animal wastes. It is estimated that almost 117 million tons of fuelwood will be consumed in India during 1990 (Chambers, Saxena, and Shah 1989). Of this amount, about 73 percent will probably be collected from common lands, from Reserve Forests, and even from Protected Forests; the remainder will be purchased (Leach 1987). Using

Previous Page Blank

1985 figures (UNDP 1986), the value of fuelwood purchased would be Rs 6.75 billion. Even ignoring the significant labor costs associated with the remaining 73 percent of fuelwood that is collected, the role of fuelwood, and its increasing scarcity and cost, in the Indian energy economy is staggering.

Another aspect of the problem can be seen with respect to the need to import energy. Average rates of growth in energy consumption in India have been about 6 percent annually since 1965, but energy consumption per capita (in oil equivalents) has increased from 100 kilograms per year in 1965 to over 200 in 1987. Over this same period energy production has grown an average of 8 percent annually. However encouraging this may seem, the serious side is revealed by the ratio of energy imports as a percentage of merchandise exports. This statistic measures, in general, the capacity of India to continue to import necessary energy resources using her manufacturing capacity to earn foreign exchange (as opposed to exporting other natural resources in order to import energy). In 1965 the cost of energy imports was 8 percent of India's merchandise exports, while in 1987 energy imports were costing 17 percent of merchandise exports. Put in somewhat different terms, India's energy imports in 1987 "cost" twice as much in foreign exchange as they did in 1965. This trend will act to restrain India's industrial and manufacturing and service sectors, where most new jobs and growth are expected in the future. Expanded hydropower sources may not be a realistic alternative (see below). While enhanced biomass stocks may not hold the complete answer to this problem, improved biomass management could offer substantial relief.

The other aspect of India's critical biomass problem is the forest cover that serves to protect watersheds for rural and urban water supplies, serves as wildlife habitat, and provides India with commercial and non-commercial timber (and minor forest products). In spite of clear evidence of biomass scarcity, official estimates vary as to the rate of disappearance of forest cover. The total forest area of India is said to be diminished by 50,000 hectares per year, though that estimate has been placed as high as 147,000 hectares per year by the World Resources Institute (1988). Other sources place annual loss of forests at one million hectares. Indeed, the very disparity of these estimates suggests the need for reliable information for improved management of the resources for India's development. Improved management of India's forest cover cannot proceed on the basis of such disparate estimates of current deforestation. Forest biomass programs are not simply the wistful desire for more trees; biomass projects represent significant economic returns: ". . . a farm forestry project . . . in Gujarat State in India . . . produced an 89 percent rate of return to farmers (Gregersen, Drape, and Elz 1989, p. 81)." On a larger scale, "Flood damage in India below the deforested areas of the Himalayan range has required emergency investments averaging

US$210 million a year during the last decade (Gregersen, Drape, and Elz 1989, p. 4)." While it is too early in the RMAT process to undertake a cost/benefit assessment, it should be clear that beneficial aspects include not only the new products made available, but also the costs that are avoided by reduced flood damage and sedimentation.

Another example of important natural resource problems is that state forestry departments face serious problems in (1) assessing the existing forest stock; (2) accommodating the needs of the commercial timber sector; (3) determining the needs of individuals living in and near the forests; and (4) setting program guidelines that will accommodate all of the demands on the forest while protecting certain areas of unique habitats of threatened species or of importance for watershed purposes. In the absence of such information, it is impossible to formulate efficient forest-management programs. Private individuals dependent upon the forest suffer. There are always serious conflicts between the use of forests for commercial use and the use of forests for villagers' needs. Forest management is less concerned with managing trees and more concerned with managing people and the demands they place on forested areas. Meeting the increased pressures for forest preservation, for the commercial uses of timber, and for community-oriented forestry places impossible demands on the data and management systems of state forestry departments. Better management information will provide a necessary first step toward improved policies and management.

Another important dimension of the biomass problem is found in the management of village common lands. It has long been recognized that the village commons is an important source of sustenance for the poorest members of a village. Recent work by Jodha indicates that for 21 (dry tropical) districts over 7 states, between 84 and 100 percent of the poor households relied on public domain lands for ". . . food, fuel, fodder, and fiber items (Jodha 1986, p. 1172)." Between 10 and 24 percent of the richer households in his study areas made use of the public domain for pond silt to enrich their fields, and for timber. But encroachment into the commons remains a serious problem. Indeed, Jodha's research indicates that public domain lands in India have shrunk significantly over the past 30 years, with some regions experiencing a loss of over 60 percent of village lands. Between 49-86 percent of these illegally expropriated lands ended up under the control of a limited group of the better-off segments of Indian society. In such cases, the illegal expropriation of the commons was often the impetus for the destruction of the native vegetation (Jodha 1986). The extent of destruction of the village commons in India is not well documented beyond these rough estimates, and new information technologies could be most useful in assessing the full extent of this problem and in helping to locate sites for immediate assistance before degradation accelerates on the remaining lands.

2. Soil Resources

Soil erosion is said to be serious on approximately 27 percent of India's land area (Panayotou, 1989). The total soil loss per hectare per year is on the order of 75 metric tons, meaning that over 6 billion metric tons of sediment are deposited in India's rivers annually (World Resources Institute 1988). Soil resource problems in India have two distinct but related dimensions. At the farm level, long-run productivity is threatened by the disappearance of valuable topsoil. This movement of soil then poses a more serious social cost in the form of heavy sediment loads in rivers. Sedimentation destroys hydroelectric turbines and threatens the ability of India to maintain a reliable hydroelectric program. Given the rising foreign exchange cost of energy imports, India cannot afford to replace hydroelectric power with that generated in oil-fired plants. Secondly, the heavy sediment load reduces the useful life of reservoirs. Finally, sediment deposits fill up river channels, thus increasing the probability and severity of floods as water overflows an ever-shrinking channel capacity.

The magnitude of the sedimentation problem can be illustrated by consideration of the following data from the Indian Irrigation Commission. The Commission undertook a study of eight reservoirs in which annual sedimentation at the time of planning was estimated, and then post-construction studies measured actual sedimentation per year.

Annual Rate of Siltation (acre feet)

Reservoir	Estimated	Actual
Bhakra	23,000	33,475
Maithon	684	5,980
Panchet	1,982	9,533
Ramganza	1,089	4,366
Tungabhadra	9,796	41,058
Mavurakshi	538	2,000
Ukai	7,448	21,758
Nizamsagar	530	8,725
totals	45,067	126,895

This threefold underestimation of reservoir siltation implies, among other things, that the economic life of these particular reservoirs is approximately one third that predicted in the cost/benefit studies that justified the initial investments. Such economic waste poses serious threats to India's continued economic growth.

3. Water Resources

In addition to the siltation problems highlighted above, there are at least two levels at which water resource management in India is suboptimal. At the micro-level one finds serious inadequacies in the management of irrigation command areas (Bromley 1982; Chambers, Saxena, and Shah 1989; Daines and Pawar 1987). The efficiency of irrigation systems in India is estimated to be in the neighborhood of 35-40 percent, meaning that the majority of the water in a major canal never reaches farmers' fields. In this regard, information technologies could be of immense benefit at the irrigation command area to help improve the management of water among farms on a system. The poor record of water management is illustrated by the fact that nearly 6 million hectares are currently waterlogged, an additional 4.5 million hectares are seriously salinized, and 2.5 million hectares suffer from serious alkalinity problems; the combined areas equal over 7 percent of India's total cropland. The interrelation between water resource policy and forestry is highlighted by the fact that over 479,000 hectares of forest land were destroyed by reservoir impoundments between 1950 and 1975.

There is growing recognition in India that the groundwater resource is being mined--village wells are going dry earlier than usual, and coastal areas face serious salination problems that destroy crops and leave the residents without drinking water. Past subsidies for the installation of pump sets have encouraged the use of groundwater for rabi cropping, but the result has been an acceleration of serious groundwater problems in many areas of the country. The central government is encouraging the respective states to enact a strict groundwater code but to date no state-level legislation exists. Part of the explanation for this delay at the state level is explained by political pressure from politically powerful users of groundwater. But an equally likely explanation is that many individuals remain to be convinced that groundwater overdraft is a serious problem. An improved system of gathering information about the condition of aquifers could play a pivotal role in furthering the passage of legislation to prevent irreversible depletion of many aquifers.

The integrated management of surface and groundwater provides the link between the two dominant water sources in India. This conjunctive management of water can occur at the farm level, at the command-area level, or at the river-basin level. Over 80 percent of India's surface water falls in the southwest monsoon between July and early September, with the remaining 9 1/2 months being almost without rainfall. There is, accordingly, a critical need for water storage for agriculture. There are, at the moment, approximately 78 million hectares of irrigated land in India, and this is expanding at the rate of about 2-2.5 million hectares per year. Yet there is increasing resistance to the expansion of the irrigated area, with

opposition coming from those opposed to the forced resettlement of peoples displaced by large dams, and from a number of environmental groups. An important strategy, therefore, is one of improving crop yields on existing irrigation systems. As suggested above, the current efficiency of irrigation systems is very low (perhaps as low as 30-40 percent), and successful water management programs on these systems is not only more cost-effective than constructing yet more irrigation systems, but would also avoid the contentiousness associated with building more large dams and irrigation systems.

The International Irrigation Management Institute (IIMI) in Sri Lanka has country-based programs to assist in such efforts. IIMI could collaborate with the Ministry of Irrigation to improve irrigation water management. At the macro-level, India is now well positioned to undertake improved management of water at the level of river basins. The Central Water and Power Research Station (CWPRS) at Pune has developed a river-basin model for the Chambal and Mahanadi Rivers that seems to hold promise for practical assistance in managing the complex task of optimal movement of water through a system. CWPRS has begun to consult with other developing countries (e.g., Ethiopia), so it is likely that this work ultimately could lead to models for optimal management of river basins in other developing countries with similar supply and demand conditions.

B. USAID's Approach

The essence, therefore, of USAID's strategy in India is to draw on the existing capacities of Indian scientists and organizations in the private and public sectors, with the assistance of U.S. scientists and organizations where appropriate, to improve decision making in agriculture, natural resources, and health. The proposed Resource Management Analyses and Technologies project, encompassing several natural resources central to India's economic future, would concern itself with the utilization and adaptation of appropriate U.S. public and private science and technology capabilities to address pressing problems of natural resource degradation.

The U.S. Government and environmental organizations have been concerned recently that development assistance programming--particularly that carried out by the World Bank--has contributed to natural resource destruction and the forced relocation (and immiserization) of millions of the poor. Indeed, it is largely due to pressure from the U.S. Government that the World Bank has agreed to be more sensitive to the environmental implications of its projects. This concern for natural resources is manifest in domestic policy where the Environmental Protection Agency has been upgraded to cabinet status in the government.

AID's strategy to promote pluralism, encourage the private sector, free up market opportunities, and promote sustainable development is consistent with the pressing needs in the natural resource sector of India. There are a large number of citizens and environmentally oriented NGOs in India who seek a voice in decision making and policy formulation (Alliband 1983). A project primarily concerned with information technologies can provide these groups with ready access to policy-relevant information. Similarly, the acquisition of information technologies can provide a significant opportunity for Indian and U.S. firms that manufacture and maintain hardware, and for those firms that write software (Bellis 1989).

C. AID Program Setting

The United States is a major trading partner with India. Yet most commercial ventures do not focus on natural resource issues directly. The environmental disaster of Bhopal highlights the risks associated with some commercial U.S. ventures in India. Intellectual property rights are also a concern as bilateral trade grows. While the private sector is a good engine for growth, adequate natural resources and certain legal controls are necessary to sustain present and future growth.

Based on past USAID/India work and the review by the team, there are a number of opportunities for U.S. assistance in the computer technology, information systems, and environmental conservation areas. These hold some promise for marrying the technical and technological advantages of U.S. entities and the needs of India to better manage its resources.

On bilateral and multilateral fronts, the United States has attempted to address natural resource problems through various projects and programs. Bilateral efforts in agriculture, forestry, water resources management, and technology development have had some success in identifying and developing pilot solutions in certain aspects of natural resource problems. For example, U.S. assistance in agricultural and educational programs aided India's green revolution success and helped lay the foundation for its current technological prowess.

Regarding the issue of sustainability, the recent AID guidance (State 039211, 2/6/90) applies to the case of India and its natural resources. Renewable natural resources perform services beyond production of food, fiber, fuel, and income such as recycling of nutrients, detoxification of noxious chemicals, purification of waters, and regulation of hydrological processes. However, as in the United States, market signals are not always the best indicators of the scarcity and importance of resources, especially when considering long-term impacts. Subsequent project development efforts should attempt to quantify the contribution of some of these non-market resources to the Indian

economy, identify specific weaknesses in the extant data and data systems, and identify sample U.S. technologies and systems that could assist in addressing these issues.

D. The RMAT Project Concept

The design of RMAT is based on the premise that natural resource policies in India are hampered by the absence of timely and appropriate management information pertinent to decisions that must be taken. For example, there is little, if any, information available on current cropping patterns in irrigation project command areas until harvest. This means that it is exceedingly difficult to estimate with precision the timing, distribution, and amount of water released for irrigation so that it meets needs of farmers. Perhaps of greater significance, the absence of early information on area planted by crop means that forecasts of various crop yields are based on very tenuous guesses. Under such conditions, management of buffer stocks, and early contacts in agricultural commodity markets, have little factual basis. The economic consequences of this situation can be serious. While the current application of scientific management procedures is often impressive, the availability of data to support those management approaches is often missing, or of such poor quality that management decisions are either untimely or inappropriate. As found during the field visit to Kerala, even such routine data as rainfall measurements are not readily available and have created major problems in reservoir design. Meetings with various natural resource management agencies--particularly water and forest resources--revealed a keen interest at all levels in a program that would enhance their management capability, and the concept of RMAT was enthusiastically received.

The RMAT project provides a unique opportunity to capitalize on, and to encourage, the budding private sector component of India's economy. There are a large number of non-governmental organizations concerned about natural resource policy, and policy-relevant information is now extremely difficult for these groups to acquire. A second vital dimension is that Indian computer hardware and software firms are poised to play a critical role in the expansion of information technologies. Particularly in the software arena, there are examples of successful U.S.-Indian joint ventures that might serve as models for more extensive collaboration in other aspects of the Indian economy. The AID-funded Program for the Advancement of Commercial Technology (PACT) promotes research and development in this area. Of equal importance, such cooperative ventures would seem to hold promise as models for collaboration in other countries where AID has similar programs. Section III of this report documents the impressive array of activities already under way. With proper programming, AID could increase its catalytic role in boosting private sector activity in India.

While RMAT is primarily concerned with information technologies, it is important that those technologies be located in an important policy context. That context is concerned with the improvement of natural resource management in India, with particular emphasis on land and water resources. The operating presumption for RMAT is that existing natural resource management efforts are hampered by the absence of reliable and meaningful management information regarding, for example: (1) existing land uses and trends in particular categories of use; (2) current forest cover and the changes in that cover over time; (3) current water use and forecasts of water availability; (4) water management in agriculture; (5) groundwater overdraft and salination in coastal regions; (6) biomass problems concerning forests, fodder, fuelwood, and common grazing lands; (7) soil erosion that destroys agricultural productivity and that leads to accelerated filling of reservoirs from sedimentation; and (8) the optimal management of river systems for flood control, hydro-electric production, and irrigation.

The overriding natural resource problem in India is to improve the quality of management decisions, whether those decisions occur in the private sector (farmers, private woodlot owners, builders, artisans), or in the public sector (government agencies). Evidence from a number of countries, including the United States, clearly indicates that efficient data collection, analysis, and dissemination will yield coherent and meaningful management information. Most importantly, natural resource data, to be useful for management, must be based upon the felt needs of the agencies and individuals responsible for making decisions regarding natural resource use. That is, the demand for data is a derived demand from the problem situation faced by the manager --whether on a farm or within a government agency. That problem situation could be ephemeral, or it could occur on a regular basis. An example of the first is the accelerated soil erosion arising from a forest fire in a particular region. An example of the second is the annual forecasting of rainfall and reservoir management over the kharif, rabi, and summer cropping seasons.

In each instance the relevant agent, whether a government official or a private farmer, must make critical decisions with important financial consequences. The need to act in a decisive way at a particular point constitutes a "problem setting." That is, the agent must choose certain courses of action on the basis of information available at that particular moment. These resource management problem settings drive the demand for better management information. Indeed, an integral component of the project will entail the determination of these problem settings at various levels within one resource agency, and across

agencies. We refer to these two perspectives as the vertical dimension (within one agency), and the horizontal dimension (among agencies). Information needs in a vertical sense are obvious enough, but the horizontal dimension is equally important--especially in India. The most obvious example arises in coordinating agricultural practices and irrigation management in the face of a failed monsoon. With early information on cropping patterns in the kharif season, it will be possible to offer improved cropping strategies for the rabi season as the strength of the monsoon becomes known. This would allow farmers to modify their rabi cropping plans early enough to arrange for seed and other inputs, and to make early credit arrangements. In short, there are large benefits from coordinated management across water and agricultural agencies when drought strikes India--an event that occurs, on average, approximately one year out of every three.

In addition, there appear to be four overarching trends in India that will drive the demand for improved natural resources information. First, democratic elections by an increasingly well-educated populace are beginning to place pressure on the executive branch of government to provide more effective and timely services to each state and local zone. Second, demographic pressure will increase pressure to maximize yields and total production, requiring reforms in water-related investment, pricing, and management systems. Third, expansion of irrigated land is becoming increasingly costly in economic terms, and in political terms as environmental groups exert pressure. Finally, current laws and policies distort resource prices and lead to severe degradation of forest, soil, and water resources. The United States is well situated to assist India in this transition to modern information systems.

The methodology used in reviewing the project concept first identified natural resource problems that appear to represent feasible activities for the application of better management information systems. Second, the team identified information technologies appropriate to that particular natural resource problem, and also technologies that are feasible in the Indian context. Third, the team assessed the most feasible geographic location for RMAT project activities. Fourth, we suggest appropriate cooperating units within the Indian private and public sectors. Finally, we suggest possible research linkages among Indian and U.S. research institutes and universities. With only 10 days (including travel) for visits with Indian organizations, a most incomplete picture has necessarily resulted of the problems, opportunities, and constraints that these particular organizations might bring to the natural resource management arena. We mention a number of organizations that we were unable to visit; the project design team will need to determine their relevance to, and interest in, RMAT.

SECTION II

THE RMAT PROGRAM SETTING

A. The Natural Resource Information Problem

While RMAT is concerned with natural resources, it is important to recognize that in an agrarian society such as India, where approximately 70 percent of the population is engaged in agricultural pursuits--and where 93 percent of water withdrawals are agricultural in nature--concern for natural resources is directly related to the nation's ability to continue to feed and clothe itself over the long run. Improved natural resource management in India is not some luxury about which there is discussion and disagreement over whether it ought to be done. The question is not whether India can "afford" to be concerned about the proper management of natural resources, but rather how can natural resource policies and programs develop and evolve so as to ensure the long-run ability of the country to depend on its natural resource base for food and fiber. Natural resource management in India, therefore, is not a matter of providing enhanced environmental amenities for the upper classes, but rather it is about protecting the supplies of food, fuelwood, and water for the poor masses in 600,000 scattered villages, and providing a sustainable flow of services to the key growth sectors in the economy (industry, trade, services). In the absence of improved natural resource management, the sustainability of India's economic growth is seriously jeopardized. Should that happen, it is the large mass of rural poor who will suffer immediately, and severely.

RMAT will improve decision systems that will lead to improved natural resource policies, improved managerial decisions being taken by the various natural resource management organizations within the Indian Government, and improved decisions by small private industries and natural resource managers such as farmers, commercial foresters, builders, artisans, and villagers in search of fodder, fuelwood, small timber, minor forest products, and livestock forage. The RMAT concept, because it is concerned with natural resource management information, will be immensely helpful in strengthening several critical ingredients in Indian natural resource policy. As long as useful management information about natural resources is missing or inaccurate, as it now is, it will be impossible for the Indian Government to formulate proper policies for ensuring that natural resource degradation is not an impediment to future economic growth. Likewise, improved natural resource information is central to the determination of the appropriate decision-making unit for certain kinds of natural resource actions. If proper information on water availability can be distributed to farmers, then they will have a better basis on which to make cropping and irrigation

decisions. To the extent that the current system is one in which only the irrigation bureaucracy has such information, then all farmers are dependent upon government agents for critical management information.

In short, the government not only monopolizes natural resource decision making, but it monopolizes natural resource management information as well. This situation is not conducive to wise natural resource management, nor does it lead to economic efficiency in natural resource allocation in various sectors of the economy. The RMAT project is crucial to promote the provision of management information not only to the public sector, but also to the private sector, so that increased managerial efficiency might result.

B. Organizational Problems in Natural Resource Management Information

We encountered a number of instances in which information problems at the organizational level hampered improved decision making in natural resources. Indeed, one rationale for RMAT is to assist Indian Government agencies to define a logic and structure for standardized data collection across the range of natural resource problems.

1. Data Collection

One serious problem is that members of Parliament make frequent requests of agencies for data on natural resource use and management. When these numerous requests are added to the current burden of providing data for the ministerial level within agencies, some field staff spend the bulk of their time collecting and compiling data for transmission up through the system. When field-level staff have little opportunity to participate in the process of defining what data are to be collected--and especially when they rarely see those data used in better decision making--the data collection system actually becomes an effective impediment to improved natural resource decision making.

There are several reasons for this unfortunate result. First, excessive data collection takes field-level staff away from potentially more worthwhile tasks which, apparently, never get completed. Second, if there is no understanding of how the data are to be used in management decisions, there is a serious risk that the data collection process will breed cynicism and lead some staff to take shortcuts so that the more "important" tasks might get completed. As a result, the quality of data suffer and bad management decisions are the inevitable outcome. We heard, on several occasions, concern for this undesirable aspect of the current system of data collection.

2. Data Dissemination

A second problem with the current natural resource information system is that all communication--regardless of the quality of the information being transmitted through the system--is vertical in nature. That is, data move up and down within the confines of a single agency but there is little opportunity for sharing data across agencies--even within the same general area of natural resource management. For instance, water resources are the logical purview of the Ministry of Water Resources and the Ministry of Agriculture, yet we saw little evidence of cooperation among these (and other) agencies in data collection, archiving, and analysis. Several aspects of RMAT will address precisely this problem.

This lack of sharing of data derives from a perception that data are proprietary; each governmental agency tends to regard its data as "private property" and it is most difficult to induce any particular agency to share data with another agency. While on the surface this practice may seem consistent with AID concerns about "intellectual property rights," it has precisely the opposite outcome. That is, intellectual property rights are of interest to those who create new knowledge that has a private market value. In such settings, the interest is to protect the embodied human capital in that knowledge and to make sure that its creator is properly rewarded for her/his efforts. In the absence of such property rights the private appropriation of economic benefits from the production of new knowledge will be impossible and much creative activity would inevitably be stifled.

But in the area of natural resource management, the economic value of information is inversely related to its hoarding and control. Improved natural resource management is a collective (or public) good, quite unlike the private-good character of an invention, or a new software program. There is no coherent economic argument to support the hoarding of information for natural resource management precisely because there is no market for that information that gives rise to appropriable economic benefits to the party in control of such information. Indeed, as intimated above, AID's goals of "open markets and open societies" are able to be met if, and only if, natural resource management information is available--at very low cost--to all parties with an interest in a particular natural resource management decision. The idea of pluralism without low-cost client-oriented public information is a contradiction in terms.

A related disadvantage of the proprietary nature of most natural resource data in India is that data hoarding leads to considerable duplication of effort. Hence, not only are good decisions rendered elusive, but a substantial amount of time and money are wasted. Ways must be found to reduce the current

duplication of effort, ensure that only useful data are collected, and establish mechanisms for sharing information among natural resource managers. Part of this problem may be overcome by innovative ways of financing the costs of data acquisition, archiving, and dissemination. Creative cost-sharing arrangements would undermine the current proprietary attitude toward data. But a more substantive analysis of the entire data system would also be required. While these latter activities may not be appropriate as an AID project at this time, we expect that successful activities under the RMAT project would be catalysts for needed changes in the current data systems.

3. Data Analysis

A third problem in natural resource management concerns the important distinction between data and information. We draw this distinction to point out that improved decision making requires meaningful and pertinent information rather than mere data. Data represent observations about certain physical or social phenomena, while information places those data into a decision context that informs the choices to be made. Many governmental organizations appear to adopt the habit of prodigious data collection without the necessary corollary activity of relating those data to a decision system. In the absence of this latter step, it is easy for agency staff to become preoccupied, indeed over-burdened, with the almost mindless compilation and transmission of numbers rather than of useful management information. This dimension, too, should be addressed in RMAT activities.

SECTION III

RMAT PROJECT OPPORTUNITIES

The RMAT project opportunities will be discussed from three different perspectives:

- o the natural and human resource problems of interest;
- o the information technologies and opportunities to solve these problems; and
- o the organizations--both private and governmental--with which collaborative efforts seem feasible and promising.

We first present a description of the natural and human resource problems, and then suggest the information technologies appropriate to each particular problem. As part of this discussion, we suggest collaborative relationships in both research and applied projects and the most probable geographic location for those activities. In sections B and C we address the relevant information technologies and collaborative relationships in an abbreviated form, and cross-reference these discussions to the major activities outlined in section A. In the jargon of information technologies, these three perspectives may be regarded as three alternative "sorts," with the first sort giving the most complete description of the project activity, and the second and third sorts serving primarily as cross-references.

The specific activities described below are intended to serve as prototypes that can be replicated in other locations as the project proceeds. We recommend an incremental approach to the project that will permit scaling up or down according to available funds. Similarly, we also recommend that a rolling design be adopted in which adjustments to project direction can be made through a biannual review, and project elements can be added or subtracted in response to changes in technology and project emphasis.

There was insufficient time to develop a detailed operational plan for phasing from the initial to subsequent activities. Also, since some of the activities presented will be modified, dropped, and others no doubt added, this design element is most efficiently addressed at the PID or PP stage. We recommend that subsequent project development efforts focus on programming the logical steps in each of the short-, medium-, and long-term phases of the RMAT project so that each phase results in either a finished product or a foundation upon which the subsequent phase will build.

A. The Natural and Human Resource Problem Focus

There are three general types of natural resource problems for which improved management information seems to hold some promise. These are: (1) biomass resource problems; (2) soil resource problems; and (3) water resource management problems. Additionally, we address several important problems related to human resources.

1. Biomass Resource Problems and Project Activities

There are four general problems pertinent to biomass resource management. First, there is the problem of assessing the standing biomass (forest, range, common lands, etc.) and of monitoring its change over time. Previous discussion revealed the wide range over which estimates of the existing biomass vary. Rational management of biomass is impossible without good information. The second problem in biomass assessment concerns the fact that the vast majority of biomass in India is not in recognized forests but is, rather, found on farmsteads, roadsides, and ditch banks. Information technologies to assess and monitor this widely scattered biomass resource present a particular challenge. Third, the serious shortage of fuelwood in major parts of India presents a unique opportunity to foster private sector development in fuelwood production and marketing. Finally, there is a need for a general program of natural resource information dissemination that would allow NGOs and private individuals to obtain information about natural resources.

a. Forest Biomass Monitoring and Assessment Activity

The purpose of this activity is to undertake a proper assessment of the status and rate of change in India's forest biomass, including timber, pulp, minor forest products, fuelwood, and fodder. This activity could be coordinated by the Forest Survey of India at Dehra Dun, and might well involve programs at the private sector Tata Energy Research Institute (TERI); our discussions with the staff of TERI indicated a keen interest in this. While the Forest Survey of India (FSI) produces various reports on the forests of India, much of the data are derived from manual interpretation of Landsat Thematic Mapper (TM) images. Recently, an image processing system was acquired to supplement these efforts. Research into the application of digital remote sensing data is under way but, consistent with previous findings (TAC 1989), development proceeds along theoretical lines and is not directed toward developing user-defined products. Geographic information systems (GIS) are viewed as a related and necessary technology. While advantages in data storage and simple correlation are anticipated, the broader potential of spatial modeling has not been examined. For example, in the United States, the consequences of alternative

management strategies for various purposes can be displayed. In one, the U.S. Forest Service must decide whether to treat spruce budworm infestations either by allowing such infestations to run their course or performing preemptive clear-cuts to contain the problem. Both produce differing results in terms of merchantable salvage timber, sediment and water yield, and recreational impacts. Assessing alternative scenarios in the form of maps allows foresters to make a better-informed strategic choice.

As part of this activity, it is recognized that much of the data currently gathered by natural resource agencies go unused, and hence it may reasonably be asked why one would seek to undertake yet more data collection. It is no doubt true that much data are simply unneeded, but improved natural resource management requires meaningful information and so it is essential that efforts be made to rationalize data collection. A good deal of data are little used because of a failure of the data to meet the needs of the ultimate users. As data-producing agencies move from manual to automated technologies of data gathering and dissemination, there is a critical need to establish data requirements for internal reporting, determine the needs of external data-consuming agencies, and select the technologies that will best meet those demands. The following tasks are recommended.

Task 1: In addition to establishing data requirements for its own internal reporting needs, FSI would contact current and projected data users in other agencies to establish a comprehensive description of desired data attributes including types of data (e.g., forest classes), format (hard copy; digital), scale, accuracy, and time of delivery.

Task 2: FSI is currently re-evaluating its inventory work in three states. In one of these states FSI would conduct a comparative analysis of the most common remote sensing systems (Advanced Very High Resolution Radiometer, Landsat MSS and TM, SPOT, systematic reconnaissance flight (SRF), and ground observation) to determine what role they might play in providing these data, both individually and in concert.

Task 3: FSI's role within the decision structure of the Ministry of Environment and Forests will also emerge in Task 1, as will its relationship with other agencies as a purveyor of data. Much of this geographic data will be in "raw" form, but much must also be refined through the application of various models (e.g., timber production or erosion potential). Based on this understanding, the role of GIS and related technologies for dealing with spatial data would be defined.

Although the need for GIS is obvious, factors beyond cost argue for an inexpensive, incremental approach to establishing a broad GIS capability within the Indian natural resource community

(both governmental and non-governmental). First, the level of awareness is relatively low and the potential will not be immediately exploited. Second, experience in developed countries (i.e., Canada) shows that the full range of capabilities found in sophisticated systems is seldom realized in routine applications. In practice, only a limited set of GIS functions is used. Thus, the power of expensive, sophisticated equipment is largely wasted in normal operations. Finally, the limited availability of equipment ensures that awareness and the ability to use these systems will grow at a relatively slow pace. These considerations argue for adoption of a rather simple and inexpensive system that could be quickly disseminated--either by the private or public sector--that would foster rapid adoption and permit easy data exchange among public and private agencies.

There are several GIS packages available within the United States that are in the public domain (e.g., GRASS, IDRISI). This RMAT project activity would evaluate GIS needs within the Indian context and select one package from the U.S. public domain. The needs of Indian organizations concerned with biomass assessment will be established in terms of display and analysis needs, and framed within likely hardware operating environments. Public-domain GIS packages will be evaluated against this background. One system will be selected. The U.S. GIS source will collaborate with an Indian private sector organization such as SRI in establishing a program of system installation and training in appropriate Indian facilities (e.g., FSI, NBSSLUP, CSWCRTI, and state departments of forestry and agriculture). Initially, the two will work together in installing GIS systems in those agencies with a demonstrated interest. Within a year, the Indian organization will assume responsibility for installation, training, and support.

Task 4: With a developed GIS, TERI could assist in selecting local units (e.g., districts) representative of key regional patterns of land use. It would conduct studies of biomass generation within the unit, and construct a simulation of alternative forms of biomass generation. It would sample other districts to determine the degree of variability in the pattern. The simulation may be appropriately represented as an expert system used to suggest alternative patterns of tree use in line with planning goals.

Task 5: The Kerala Forest Research Institute (KFRI) at Peechi is the nation's only state forest research center and provides important services, especially regarding production of commercial wood crops. This task would upgrade KFRI to undertake biomass monitoring and assessments. The main problem is that data from field trials are collected by hand and put into a mimeographed form. At the end of the trials they are submitted to the central office of KFRI in Peechi. There is a lapse of as long as a year before the data are analyzed.

There are several reasons for this delay:

- o the need to schedule scarce time on the computer;
- o the manual entry of data;
- o the need to program the results; and
- o the fact that the statistician is not a forest researcher, and the forest researcher is not a statistician.

All of the programming is done in FORTRAN and it takes as long as two months to program a cluster analysis statistical procedure. Much of the statistician's time is taken up explaining a statistical procedure to the scientist who wants to use it in his project.

We envision upgrading data collection and analysis efforts by a combination of training and hardware and software. This could be accomplished by implementing a simple automated data-collection procedure to reduce the amount of time required for data collection.

Additionally, we would increase the hardware capabilities via processor speed, memory, and storage. Also, the station should acquire off-the-shelf statistical software packages, one of which should be a powerful, general purpose package such as SPSS or SAS. We would also urge the acquisition of add-on packages to perform the specialized statistical procedures used by the scientists. Finally, it would be necessary to train staff in the use of advanced statistical procedures appropriate to their specialties.

b. Farm-Based Biomass Inventory and Monitoring Activity

While there is much debate about the extent of India's remaining forested area, the bulk of woody biomass in India is to be found on small woodlots and plantings within and around farmers' fields, as well as on roadsides and canal banks. In the case of fuelwood, it has been estimated in the past that perhaps as much as 85 percent comes from non-forest lands (GOI 1962). These data suggest that the situation is ripe for increased private sector involvement in biomass programs. However, these dispersed sources of biomass present special problems in developing an effective inventory and monitoring scheme. In spite of increased reliance on kerosene, fuelwood will continue to be a mainstay in India's energy economy in rural areas (Chambers, Saxena, and Shah 1989). There are frequent discussions regarding fuelwood marketing enterprises to help expedite the efficient matching of deficit areas with those regions of ample supply. There is thus a compelling need to

understand the total production--and spatial dimensions--of fuelwood so it can be efficiently managed. This project activity would start by focusing on the fuelwood biomass.

While data from satellites and aerial photography form the basis of the forest inventory system, this proposed "National Fuelwood Information System" would be based on a multistage sampling strategy using a combination of satellite images, aerial photography, and ground sampling to produce estimates of fuelwood production and, subsequently, a model of fuelwood production and distribution. This information would be used to assist in the planning and organization of private sector fuelwood marketing enterprises that have been proposed. Other types of biomass (range, forest, and common lands) could be inventoried and product marketing firms promoted if feasible. The PID or PP team should evaluate the possibility of these alternatives.

Task 1: Through the FSI, two or three states of differing ecology would be selected for study (say, Maharashtra, Kerala, and Rajasthan). Using satellite data, each study area would be divided into units (strata) that are reasonably homogeneous in terms of their production potential and agricultural systems. Large-scale aerial photography would be acquired to estimate the area devoted to wood production. Ground sampling would be done to determine wood type, size class, and volume.

Task 2: A fuelwood production model would be developed using data gathered from selected farms. The dynamics of on-farm wood production would be established in terms of:

- o total annual production;
- o variety of products (fodder, fuel, poles, lumber);
- o economic value; and
- o feasible markets.

Task 3: A geographic information system would permit the inventory and model to be used to develop a display of a state's "woodshed" and how it varies in response to changes in production and demand throughout the year. These data would be used to identify optimal sites for new plantations, as well as ideal locations for collection and distribution points.

c. Biomass Processing and Marketing Activity

The biomass assessment activity outlined in the previous section, while concerned with the assessment and monitoring of biomass, would not address important questions regarding the encouragement of biomass production by farmers and others in the private sector. The proposed "Biomass Processing and Marketing Activity" would link the successful applied biomass research program of the Bharatiya Agro-Industries Foundation (BAIF) at Pune with the analytical skills of the staff at the

Tata Energy Research Institute (TERI) in Delhi to develop an extension program to teach farmers the economic advantages of producing and marketing biomass for fuel, fodder, forage, and minor timber products.

Task 1: BAIF and TERI would collaborate on the development of client-oriented decision systems that would become the basis of farm-level planning for biomass production.

Task 2: TERI would take the lead in developing a biomass marketing program for computer applications. This program would be used by BAIF and TERI in identifying particular regions facing the most serious biomass shortages and relating these regions to areas holding potential for increased biomass production. The deficit and potential supply areas would be linked in a model that would determine optimal market channels between the two.

Task 3: BAIF would collaborate with state forestry departments to develop a viable nursery program for its biomass development and extension program. This program would entail seed production and distribution through schools, agricultural extension workers, and BAIF's own biomass production and marketing program.

Task 4: BAIF would take the lead in developing an extension program to encourage the production and marketing of biomass based on this optimal marketing model. The early phase of the activity, say the first five years, should be limited to a few states where BAIF has a significant presence (Maharashtra, Gujarat, Karnataka, Andhra Pradesh, and Madhya Pradesh). As the activity is perfected, it could be expanded to other states in India.

Task 5: To assure the replication of this activity, BAIF would undertake a series of regional workshops. These would be aimed at assisting other NGOs and the private sector in establishing similar activities in other states.

d. Natural Resource Information Dissemination

A great deal of information on a host of development problems is generated within India by various agencies. Some information appears in national and international journals, but more is contained in reports with very limited distribution. This "grey literature," often a rich source of information for practical or regional experiences, is virtually inaccessible to the larger development community. The need for information exchange is well recognized among research and development groups, but the problem appears to be especially acute among those concerned with natural resource management.

International bibliographic databases provide access to significant work done by groups outside India. In addition, groups within India are developing computerized databases of their own work. In Europe and North America, national and local bibliographic databases such as these are routinely searched "on-line" for pertinent material using personal computers tied to conventional telephone lines. While reliable telecommunications is almost essential in gaining access to these resources, it is highly unlikely that the Indian telecommunication system will be able to support routine data transfer in the near future.

This project activity would establish an "Indian Development Information Exchange System" (IDIES) for the dissemination of management information. A model for information exchange is evolving among NGOs in India. For example, ICRISAT and BAIF have both acquired the Commonwealth Agricultural Bureaux (CAB) abstract collection on compact disk (CD-ROM) that provides them with access to international bibliographic information. In addition, both have implemented the UNESCO CDS-ISIS database management system to organize their own library collections. They have agreed on a common format and thus can exchange data via floppy diskette. Similar systems of information public/private exchange have been installed in other countries (e.g., Niger, Kenya, and Yemen) by U.S. organizations (such as the University of Arizona), with sponsorship by USAID and UNEP.

Task 1: With an NGO serving as nominal lead, an informal network of research and development centers would be established for information exchange. All agencies involved in natural resource management would be invited to join the network, but participation would be voluntary. At an initial meeting, participants would select a common software (e.g., CDS-ISIS) and uniform exchange format. Information (i.e., diskettes) would be distributed among participants on a regular basis (say, biannually). Regional nodes may be selected within the system for installation of CD-ROM-based systems to provide bibliographic services to nearby or related stations.

2. Soil Resource Problems and Activities

There are three general concerns in improving the management of soil resources. First, information technologies can play a critical role in improving the farm-based soil conservation efforts of millions of private farmers. Second, there is a need to identify groups of private farmers in particular catchment areas where soil conservation programs will have a large payoff in terms of reduced reservoir siltation. Finally, information technologies can be essential to the efficient selection of new venues for focused soil conservation projects.

a. Farm-based Soil Conservation Activities

There is now a rich informational base in India concerning soil conservation measures that can be employed by individual farmers. Additionally, the international literature contains the results of thousands of cultural practices for reducing soil runoff. This project activity would involve the Central Soil and Water Conservation Research and Training Institute (CSWCRTI) at Dehra Dun in collaboration with state departments of agriculture to disseminate practical, client-oriented farming systems to reduce soil erosion.

Task 1: CSWCRTI would serve as the clearinghouse for the literature on soil conservation. This information would be compiled in bibliographic form (including abstracts) for distribution to extension units in state departments of agriculture.

Task 2: Extension training programs would be expanded at CSWCRTI to bring in more extension agents from selected areas throughout India for intensive training. These extension agents would be selected from particular areas where soil erosion is a serious problem, and where state agencies have made soil conservation a central program focus. Trainees would observe research plots and results, learn about the engineering aspects of soil conservation, and receive special training on the socioeconomic aspects of farmer-oriented extension work on soil erosion.

Task 3: Trainees would receive special instruction on accessing the international database being managed by CSWCRTI. This training would include not only accessing the data set, but training in ways to search various databases for pertinent information.

b. Catchment Area Management Activities

A wide array of analytical tools is available for transforming natural resource data into information upon which decisions can be made. Many of these tools have been developed and implemented in other countries, but many have also been developed in India. Due to the difficulty of applying these tools in a spatial context, and the limited availability of computers for natural resource management, most are not widely used and their potential is not generally appreciated.

In this project activity, we urge that the Government of India undertake implementation of the Water Erosion Potential Program (WEPP). CSWCRTI deals with the problems of soil and water conservation on a project scale through a program of research and training. A primary focus of its activities is erosion control through intensive watershed management. While

some techniques for estimating erosion are in use (for instance the Universal Soil Loss Equation--USLE), they are only gross estimators and generally treat watersheds or sub-watersheds as a single unit. Such estimates are useful for monitoring, but they lack the precision and geographical specificity necessary for targeting labor- and capital-intensive investments at the micro-watershed level of two to three villages.

The U.S. Department of Agriculture (USDA) is preparing to release a new WEPP that will replace the USLE. CSWCRTI has established collaborative ties with the USDA Southwest Watershed Research Project (SWRP) and the University of Arizona School of Renewable Natural Resources (UA/RNR) to receive WEPP. At present, however, CSWCRTI lacks the computing power to implement WEPP and the broader expertise in spatial modeling to fully exploit it.

Task 1: CSWCRTI would collaborate with USDA/SWRP to implement WEPP in the Indian environment. Thus, CSWCRTI would receive the model it needs to improve its erosion prediction work, and USDA would have the opportunity to observe WEPP performance as part of its worldwide field verification program.

Task 2: As part of the first task, a GIS would also be developed at CSWCRTI in collaboration with UA/RNR. Beyond serving as an archival system for storing geographic data, WEPP and other models would be implemented (e.g., timber and fuelwood production, and erosion control optimization) so that alternative development scenarios can be assessed.

c. Information Technologies for Soil Conservation Site Selection

A serious problem exists in that there are no coherent procedures for selecting feasible locations for the implementation of successful small-scale development projects that foster soil conservation. For instance, the village of Sukhomajri, near Chandigarh, is often cited as a very successful intervention that shows how soil and water conservation techniques can lead to vastly improved productivity and income (Grewal et al. 1989). It is clearly worthy of replication in other erosion-prone locations. However, there is no consensus as to the conditions that contributed to the success of the Sukhomajri model and, therefore, the Indian Government is unable to identify suitable locations for replication. This project activity would be concerned with the development of expert systems for selecting suitable sites for micro-watershed erosion control/water harvesting projects.

Task 1: CSWCRTI at Dehra Dun would take the lead in this activity by establishing a Social Science Department consisting of doctorate holders in anthropology, agricultural economics,

sociology, and public policy. This social science capability would be harnessed to undertake a detailed analysis of the cultural and socioeconomic characteristics that seem to contribute to the adoption of successful natural resource interventions at the village level. Various quantitative techniques can be employed to survey and analyze a large number of villages--both failures and successes--and then other techniques (i.e., discriminant analysis) can be used to select candidate villages for intensive soil conservation and agricultural extension work. Additionally, this activity will help to highlight those government policies and regulations that serve as barriers to effective sustainable management practices (e.g., lengthy administrative procedures for granting permission to harvest wood).

Task 2: The social factors ascertained under Task 1 are the necessary conditions for a successful activity, but they are not sufficient. The sufficiency test consists of natural resource inventories and land-capability assessments to develop plans for soil conservation structures, field leveling and cropping plans, and extension programming for increased production and marketing of the agricultural commodities. This work would be undertaken through cooperation among CSWCRTI, NBSSLUP, and the relevant state agriculture departments.

3. Water Resource Management Problems and Activities

In the field of water resource management problems, there are three general classes of concerns. First, information technologies are essential to the development of micro-watershed design and management decisions. Secondly, river-basin systems require reliable and timely access to data to facilitate management, as well as to plan future investments. Finally, information technologies are crucial to comprehensive water resource management across program areas and across agencies. We propose here several activities related to the acquisition, analysis, and dissemination of information to aid in the conjunctive use of surface and groundwater, to provide early warnings of impending groundwater depletion (and/or salination), and to serve as an early warning system for possible fuelwood shortages.

a. Decision-Support Systems for Improved Micro-system Design and Management

The Central Water Commission (Ministry of Water Resources) currently reviews and approves water projects proposed by the various states of India. If a state does not have technical capabilities to do the planning and design, the CWC will provide these services. This activity includes tasks that will streamline this process and increase the likelihood of design of successful micro-system water-management projects.

Task 1: We propose to replace the existing paper-based engineering drafting system with a PC-based computer-aided design/drafting system (CADD). Such a system uses a PC to create design drawings. It displays the design drawings on a computer monitor, or it produces final drawings for construction with a pen plotter. A CADD system stores the drawings in machine-readable form for subsequent use. Under the proposed scheme, the plans and specifications would be transmitted between states and the CWC on a PC diskette. When CWC reviews state-developed plans, the modifications can be made by state engineers with the CADD system, and the final plans can be drafted automatically. Further, commonly used design details can be developed by CWC or state engineers in machine-readable form and shared among the states simply by mailing a diskette from place to place.

Task 2: We propose that application of a watershed erosion software program, such as WEPP, be adopted in all future reservoirs built with public funds. Such a program would be used by the Central Water Commission in its review of its own projects, as well as those submitted by state governments.

Silting of irrigation water reservoirs limits the useful life of these reservoirs. By reducing the life of the reservoir and thus the electricity and irrigation it provides, the payback projections on which the reservoir was justified and financed will no longer hold and the project will fail. In some cases, rapid siltation may be unavoidable. However, with sufficient information regarding erosion potential, site selection and/or reservoir design can be vastly improved. Of course, the proposed analysis will not eliminate siltation of existing reservoirs, but it will lead to greatly improved reservoir site selection and design. This task is related to a task in the catchment area management activity.

b. Decision-Support Systems for Improved Macro-system Design and Management

There is a promising opportunity for improved large-scale water system management through application of systems analysis. This activity calls for application of systems-analysis tools to develop decision-support systems for surface water and groundwater resources.

Task 1: We propose to improve river basin management through improved modeling of reservoir and canal operation. This supports the work of the Central Water and Power Research Station (CWPRS) through broader collaboration among agencies with systems-modeling experience in the United States. Likely U.S. collaborators included the Central Arizona Project and Salt River Project (Arizona), Tennessee Valley Authority, Bureau of Reclamation, Corps of Engineers, Texas Department of Water Resources, and California Department of Water Resources. In

fact, at least two of these organizations have previously worked on short-term projects with CWPRS. In any case, however, we suggest that the modeling efforts be truly client-oriented, rather than academic exercises.

Task 2: The current river-basin modeling work should be expanded to include combined surface-water/groundwater systems. This particular technical area is receiving much attention in the United States and many organizations have ongoing research and development programs. The Corps of Engineers is a potential collaborator.

Task 3: We suggest supplying 80386 microprocessor computers to the CWRDM in Kerala for the divisions of surface water, groundwater, water management, and water quality and environment. These computers will be used to develop simulation models of rainfall-runoff processes, estuarine dynamics, groundwater movement in low-transmissibility lateritic and hardrock aquifers, and construct meteorologic, hydrologic, and hydrogeologic databases for Kerala State.

c. Data and Information for Micro- and Macro-System Decision Support

Water availability estimates are required for allocating water with current water control works, and for planning future works. Hydrologists must have high-quality rainfall and streamflow data to provide reliable estimates. In India, most hydrometeorological data are collected by direct observation. A technician travels to the data-collection site, measures rainfall or streamflow, records the observation, and transmits the result to the analysis site. Depending on the need for the data, the transmission occurs monthly, daily, or in near real-time via telephone or wireless. However, such data collection is error prone and unreliable: access to the site may be difficult, interpretation of the observation is subject to human error, the technician may not be available when data are required, and telephone and radio transmission are not reliable. We propose application of recent technological advances to overcome some of these difficulties.

Task 1: We propose an automated data collection and transmission scheme that includes automated rainfall and streamflow data collection stations with data loggers for data that are not required in real-time (immediately upon collection), and automated collection-transmission stations for data that are required in real-time. According to Mr. Shah, Chairman, the Central Water Commission has implemented a scheme for dynamic regulation of canal systems. In conjunction with this scheme, the World Bank has funded a project for national water management that will develop computer programs that will recommend optimal distribution policies in near real-time. However, to do so, the

software programs must have access to reliable hydrometeorological data in near real-time. We propose to extend the automated data collection scheme to included automated data transmission. This scheme, managed through the Central Water Commission, will be integrated with the World Bank project to ensure that data are available for the software programs developed. These efforts would be linked through a common data-storage system; data collected as a result of this effort will be stored in a system accessible to the programs developed in the World Bank effort. For data transmission, wireless, satellite, or similar technology can be used.

Task 2: We propose support for development of an expert system for data screening. Data collected, regardless of the method of collection, are subject to error. Such errors can be costly. For example, if rainfall data are measured inaccurately, runoff estimates will be inaccurate. If runoff estimates are inaccurate, reservoir design will be incorrect. If reservoir design is incorrect, project features will not function. The team saw one such case in Kerala, where a reservoir has failed to fill so as to permit full and effective operation of the installed hydroelectric facilities. Due to the lack of accurate rainfall data, the reservoir project was over-designed by perhaps a factor of three.

Often these errors in data are obvious to specialists in the field. For example, when tree dimensions are measured at the Nilambur sub-center of the Kerala Forest Research Institute, scientists know to expect certain rates of increase. If the data do not fall within an envelope defined by these expected rates, the data collected is suspect. An expert system may correct this. An initial application will be selected by a panel of Indian and U.S. experts. This application could be one in which data are collected by field observation in which there is a known history of error, but for which there is a body of knowledge for identifying potential errors. The KFRI example is one potential application. Screening of rainfall data collected by the Indian Meteorological Department is another candidate. Then, appropriate software and hardware will be acquired for implementing an expert system. The software will include both expert system and database management programs.

Task 3: Expert systems should be developed for on-site recommendation of alternative land and water management techniques undertaken at CWRDM in Calicut. An appropriate example would be to take the results of current research on water flow through laterite soil formations to supply a set of recommendations for electric pump selection in the conversion from manual to pump-lift wells. The second stage would be to implement the expert systems on battery-powered portable (lap-top) computers. These systems would then be distributed to an NGO contracted for this purpose. This will permit the results to

reach a broad client base, as the NGO provides on-site, on-call consulting to individual farmers or enterprises who plan to install pumps. This private sector emphasis will provide important opportunities for improved natural resource management.

Task 4: An early warning system should be developed for natural resource problems. Examples of potential application include salt-water intrusion in coastal aquifers, early stages of sedimentation, and incipient fuelwood shortages. This early-warning system would be linked to a national communications system that would transmit natural resource information nationwide. Possible linkages include the Central Groundwater Board, the Ministry of Water Resources, and state forestry departments.

4. Human Resource Problems and Activities

A major problem in natural resource management in India, and one that new technology alone will not solve, is the capacity of human resources involved at various phases of data collection, data management, and data analysis for enhanced decision making. While improved data are necessary to improved policies, they are not sufficient. True managerial reform will come only from successful efforts to improve the human component of the decision system. Therefore, improvements in the management of human resources represent a critical area for action. Such efforts are usually thought of as enhancing the technical capacity of the professional staffs of land, forest, and water management agencies. We suggest an expansion of the scope of these efforts to include a wider range of target groups that encompasses farmers, villages, and NGOs, and an expanded vision of resource capacity to include the social contexts of resource management.

One dimension of the problem is the need to capture and disseminate indigenous knowledge of resource use by local managers--be they household heads, private enterprises, or communities. While much of what farmers, enterprises, and villages do may result in resource degradation, not all of it is seriously damaging over the long run. Traditional practices often are a sustainable but ignored source of resource management knowledge. We advocate the capture of this knowledge and its communication to resource scientists, outreach workers, and culturally and socially similar populations where such knowledge has been lost. This entails tapping the specialized knowledge of local experts such as successful farmers or elderly individuals who retain an oral history of land and water use. It also includes the capture of shared knowledge of environmental variables (local soils, vegetation, and microclimate) as well as the informal institutional mechanisms created by communities for the management of common resources.

A second dimension of the problem is the need to bring local knowledge to the attention of the professional staff of natural resource management agencies whether they manage state-controlled resources (e.g., government forests) or carry out basic or applied research for local managers. In addition, professional staff need to be made aware of the dynamics of small communities and businesses (e.g., artisans and wood contractors) that bear on resource management, such as the adoption of innovations, group decision-making, social organization and social structure, and the effects of religion and caste on the adoption process.

A third aspect of the human resource problem relates to the environmental NGOs. NGOs play an important, if often contentious and controversial, role in natural resource management policy. They are hampered in their contribution to national debates by a lack of the technical expertise that resource scientists command, and by difficulties in gaining access to the relevant data and information used to generate natural resource policy.

An editorial in the January 18, 1990 Indian Express suggests that " . . . such people [environmentalists], concerned with the human as much as the natural environment, are often the first to expose the fraud and corruption [of natural resource development projects] . . ." The editorial further points out that "[t]oo few . . . of our 'environment saviours' are professionals, that is people with expertise, committed to facts not biases."

We suggest that this project activity attack the problem of human resources within the general arena of water management. The Government of India has placed a high priority on improving water management--it will be a key element in the next five-year plan and is also recognized by major lending agencies as of the utmost importance. Our experiences suggest that the Centre for Water Resources Development and Management (CWRDM) in Calicut, Kerala, is a likely candidate to implement several of the tasks under this activity. By focusing on the small-scale communities of households that constitute the social context of CWRDM's clients, control and responsibility over the research agenda will be transferred to the users, including farmers and other resource-based industries such as wood contractors and producers of rubber, coconut fiber, and reeds. Inasmuch as this activity addresses a problem common to most water, forest, and land research departments at the state level, the activity constitutes a prototype that could be implemented at the Kerala Forestry Research Institute, and eventually on a wider scale.

a. Inventory and Dissemination of Current Practices and Community Dynamics

In state resource management departments, social contexts of resource use are often confined to estimates of the monetary costs and benefits of alternative management strategies.

While economic aspects are an important part of an action-oriented research agenda, scientists and outreach workers lack access to local knowledge and an understanding of the social dynamics of their client communities. This activity would address that problem.

Task 1: Inventory ongoing water management practices. This will entail collecting relevant ethnographic and historical literature of shared and specialized local knowledge of water management, isolating areas for the acquisition of knowledge, and conducting requisite field studies. To support this activity, a sociologist and/or anthropologist will be required and supported with a microcomputer and data-management software.

Task 2: Transfer current practices to a management information system. This will include compiling a well-documented set of case studies for use in training (see below), a database of the local water management knowledge and, where appropriate, expert system representation of successful local solutions to common water management problems.

b. Interdisciplinary Training for Water Engineers

The responsibility for planning and design of water projects falls on civil and agricultural engineers. The technical training of these engineers in India is on a par with that offered internationally. However, the success of a water project does not depend solely on technical factors; it depends equally on social, environmental, economic, political, institutional, and financial factors. In India, as in the United States, little training is available to develop in engineers the skills to incorporate properly these factors in their planning and design activities. This project activity seeks to develop these skills through a post-graduate training program. The direct payoff will be better planning of water resource investments at a considerable savings in time and financial resources.

Task 1: Develop a curriculum for a series of one-week extension courses. The curriculum should cover fundamentals of resource economics, environmental assessment, and social and institutional analysis. It should have a definite, obvious, case-study focus. The curriculum should be developed by a panel that includes U.S. and Indian resource economists, ecologists, anthropologists, water engineers, and post-graduate education specialists. The same panel should be charged with evaluating periodically the success of the training program.

Task 2: Establish courses as a regularly offered part of in-service training for both junior and senior officers in state water resources departments. The need for multidisciplinary

training is not obvious and, until it is understood and accepted by senior officers, it will not become institutionalized.

Task 3: Develop a university curriculum to introduce fundamentals of resource economics, environmental assessment, and social and institutional analysis to students in water engineering.

Task 4: Extend the courses to other resource management agencies, such as the state departments of forestry. As mentioned above, this type of training program could be applied to forestry and land management agency staff. As there was no forester on the project concept review team, it was premature to recommend a detailed plan for interdisciplinary training for such staff in India. Further, the issues of recurrent costs, possible impacts, and alternative private sector delivery mechanisms need to be explored at the PID and PP stages of project development.

c. Technical Training for Environmental NGOs and PVOs

Just as the preceding activity sought to provide training in the social sciences to engineers, this project activity would enhance the technical expertise of NGOs and PVOs through a post-graduate training program.

Task 1: Develop a curriculum for a series of one-week extension courses. The courses should describe, in non-technical language, the technical factors involved in planning and designing natural resource projects. An example of such a course is offered by the University of California, Davis Extension, to increase community knowledge of flood-water management in Sacramento. As above, this curriculum should be developed by a panel that includes U.S. and Indian resource economists, ecologists, anthropologists, water engineers, and post-graduate education specialists. The same panel should be charged with the periodic evaluation of the training program.

Task 2: To ensure broad participation, a consortium of NGOs (e.g., TERI, the Centre for Science and Environment), government agencies (e.g., MEF), and professional societies should be selected to coordinate presentation of the courses.

d. Professional Society Support

Many government agencies in India have professional staff performing similar technical work. For example, hydrologists at the National Institute of Hydrology, the Central Water Commission, the Center for Water Resource Development and Management in Kerala, and the Indian Institute of Technology, Delhi, are researching the rainfall to runoff transformation. However, these professionals are not able to communicate the results of their research in a timely manner. We propose a

strengthening of selected professional societies to foster interchange of research results and information on application successes and failures. Because such societies involve professionals from every sector, this will also serve as a vehicle for greater exchange between the public and private sector. Tasks include the following:

Task 1: A single society will be selected as the model for this activity. We propose the Indian Water Resources Society (IWRS) for this project. A linkage with a U.S. counterpart will be established. For IWRS, this might be the American Geophysical Union or the American Society of Civil Engineers. A nationwide membership campaign will be mounted to maximize the spread of information. With the assistance of professional staff and volunteers from the U.S. counterpart, the existing operation of the Indian society will be reviewed. This includes the society journal and periodic society conferences. Based on this review, the Indian society will be encouraged to implement appropriate operational changes. These changes may include improvements to the journal, establishment of a nationally distributed newsletter, development of local society chapters, establishment of special-interest groups with the society, organization of frequent specialty conferences, and establishment of conference-travel fellowships. Further, this would strengthen the society so that it may take a more active role. That is, it might:

- o propose professional standards;
- o recommend training curricula;
- o lobby for legislation; and
- o inform the public of major issues.

The society should be self-sufficient within a negotiated time frame.

Task 2: The model society will, in turn, work with other professional societies to improve their capabilities. Successful expansion beyond the first society will require similar participation in other technical areas.

B. Technical Opportunities and Issues

Information technologies offer at least three distinct opportunities to address the natural resource problems outlined in the preceding section. First, information technologies can speed the collection of data and help ensure quality. Second, through the use of data management and analysis tools, the amount of time invested in routine data reduction is reduced and the quality of decisions is improved; managers can spend less time on trivial tasks and more on meaningful analysis. Finally, with many shared computer-based tools and data contained in a digital format, movement of information within and between agencies is facilitated.

In this section, we define the various information technologies that are appropriate and reexamine the activities proposed to deal with these problems in the context of the information technology to be used. However, underlying the technical opportunities are larger issues of information access and management that jeopardize the long-term viability of many solutions. Where necessary, we discuss these also and suggest how they might be resolved.

As described in an earlier consultant's report (Bellis 1989), there are at least six classes of tools that might be assembled in a client-oriented decision support system. These include: (1) productivity tools; (2) database management systems; (3) geographic information systems; (4) simulations and models; (5) expert systems; and (6) mass storage systems (i.e., optical). Because we have chosen to deal with the entire spectrum of activities involved in translating data into informed actions, we have added data acquisition systems as a seventh area of information technology.

1. Productivity Tools

In developed countries, a host of computer-based tools have transformed the office workplace by automating and enhancing those activities formerly done by hand. These include word processing systems (WordPerfect, Wordstar), spreadsheets (Quattro, Lotus 1-2-3), desktop publishing systems (Ventura), display graphics (Showpartner, Micrograph Designer), integrative statistical packages (SPSS, SAS), and Computer-Aided Design and Drafting (CADD) systems (AutoCAD). In fact, the list of potential productivity-enhancing tools is growing so fast that keeping abreast of advances is itself a major challenge.

For the proposed project, a set of productivity tools would be recommended for every computer installation that would serve two purposes. Obviously, these tools must first meet the purpose(s) for which they were designed and thus enhance an individual's ability to perform specific tasks. Second, and perhaps more importantly, these tools serve as a convenient entry point for users with no previous computer experience. That is, users begin with well-known tasks (e.g., typing) and move forward from there. Third, these tools should eventually lead not only to competency in the use of the specific package, but an overall institutional computer "fluency" so that adoption of new tools becomes a fairly routine process.

2. Data Acquisition Systems

Data acquisition systems encompass a wide array of instruments that are used to gather primary data. They form the basis of any information system, and include everything from automated stations that record rainfall and temperature to

satellite-based remote sensing systems that image the earth. In keeping with a long and conservative tradition of resource management, Indian agencies gather vast amounts of data. It can be argued that some data are superfluous, but there remain legitimate data needs that are not consistently met due to high acquisition costs or poor quality control in data gathering at the field level.

a. Automated Instrumentation

Automated instrumentation provides opportunities to gather automatically, on the ground, data that are traditionally gathered by human observers. Automated data loggers simply record the data for later retrieval, while data transmission devices record the data and transmit it to a central site for analysis. As recounted previously (section 3.c), the lack of accurate data can be costly, causing reservoirs to be incorrectly designed. Automated data collection has potential in the forestry biomass assessment and monitoring activity (see section 1.a), and in the activity concerned with data and information for decision support in water resource management problems (section 3.c).

b. Remote Sensing

Satellite remote sensing offers an inexpensive source of data for documenting land surface conditions (e.g., land use, forest cover) for large areas in a very short time. Satellite remote sensing technologies are coming into wider operational use in India (FSI, NBSSLUP). However, the relatively low spatial resolution of satellite systems restricts their use in local applications. The adoption of multistage sampling techniques, which use several types of remote sensing data and ground sampling, can overcome many of these limitations and may reduce operating costs by reducing the number of required ground samples (see sections 1.a and b). Similar techniques are used by the U.S. Department of Agriculture to estimate annual major cereal production, monitor natural resource assessments on a five-year basis, and inventory timber and fuelwood resources approximately every 10 years.

The success of any inventory and monitoring activity based on remote sensing hinges on free and immediate access to satellite images and aerial photography. Within Indian natural resource agencies, there are conflicting reports of slow delivery of satellite data. Perhaps this issue is as much a function of individual persistence as of bureaucratic inertia. More significant are the large areas of India ruled off limits for any remote sensing data due to national security considerations. Restricted access will reduce the effectiveness of any national monitoring system. There does not appear to be any solution to this problem.

3. Database Management Systems

Database management systems are a broad class of tools used to store, sort, and recombine tabular data sets. Together with productivity tools, they represent the most common and useful type of information technology currently available.

a. General Purpose Systems

Better management of the large volume of data currently generated by natural resource management agencies in India is at the heart of any proposed decision-support system. Along with productivity tools, general use of simple spreadsheet programs, such as Lotus 1-2-3 or Quattro, would probably do as much as any other set of interventions to enhance the quality of data analysis, speed the movement of information within and among agencies, and contribute to better and more timely decisions at every level of management. Essentially all the activities proposed will include database management systems ranging from general purpose databases or spreadsheets to systems designed for specific uses.

b. Special Purpose Systems

Special purpose systems are justified when the volume of material to be managed is high and there is a need for uniformity to facilitate data exchange among agencies. The need to gain a better understanding of the scope of work under way in India is a universally voiced concern. In North America, this could be done through commercially available databases and, in fact, this avenue is being pursued by several agencies (e.g., BAIF and ICRISAT). However, the level or awareness in most groups and the condition of India's telecommunications system does not make this a universally appropriate approach. A reasonable alternative in achieving a better flow of information among agencies is to provide them with a means to organize the bibliographic materials (i.e., current holdings, published and informal reports, etc.) contained in each research, training, or executive facility so that they can be exchanged by mail (see section 1.d).

c. Issues

It is not uncommon for an agency to treat the data it generates as proprietary and to deny, delay, or restrict access to it. It is highly unlikely that much can be done to overcome this problem in the short term. In the medium term, agencies should better identify the consumers of the data they produce and work with them in determining the final form and content of their product before bringing an operational program on line (see sections 1.a and b). In the long term, agencies should systematically examine their own needs and obligations to

establish a coherent internal data management policy. Given probable budget constraints and increasing demands in the future, it is not unreasonable to recommend the formation of a data management policy unit within each of the natural resource management agencies for this purpose.

Much of the data currently gathered go unused. Although unmeasured, the costs of data collection, storage, and dissemination are undoubtedly high. There are, moreover, data that are of broad and critical interest and thus in some demand. To ensure that data are collected and disseminated quickly to the most interested agencies, the principle of interagency cost-sharing should be introduced.

4. Geographic Information Systems

Geographic information systems (GIS) are a special class of data management systems in which the spatial location of items in the data set is a primary attribute. Most often, data are entered and managed as maps (e.g., forest types), but tabular data also may be entered and displayed as either a map or table (e.g., state timber production by district). As used here, GIS differ from automated cartographic systems in that they incorporate analytical capabilities (e.g., surface generation and map overlay) in addition to graphic storage and display of map data.

Virtually all natural resource management problems have a spatial dimension. Many of the analytical techniques currently in use lack the geographic specificity needed to select sites for interventions that will produce the maximum benefit for the least cost. Because spatial analysis is such an awkward task to perform manually (e.g., overlaying several maps and displaying regions of congruence), automation of the process permits assessments that were previously impossible. Thus, as in database management, the need to establish a GIS capability in natural resource management agencies is addressed in most of the activities described here. As in other agencies worldwide, the need to incorporate these considerations through a GIS is well recognized in most Indian organizations and is being actively pursued by many (e.g., FSI, SRI, and NBSSLUP). Unlike many other information technologies, India appears to have realized the potential for GIS relatively late.

a. Issues

Like other specialized database management systems, there are large packages commercially available. Unlike other special systems, however, the GIS selection is limited and the price of the most widely used system is exceptionally high. To have maximum impact, a single, simple public-domain system

should be selected and implemented at a national scale. From the base of expertise that would be established, more sophisticated systems could be implemented incrementally as needed.

5. Systems Analysis Models

We wish to distinguish between two types of mathematical models. Descriptive models tell the user what will happen if certain decisions are taken, or if certain events occur. Prescriptive models tell the user which decisions must be taken, or which events must occur, to achieve a desired goal. Descriptive models are used to predict the behavior of system elements (e.g., runoff in a hydrologic system) under a given set of conditions (e.g., soil type, soil moisture, slope, vegetation cover, and precipitation). In contrast, prescriptive models are considered as related tools used in planning to optimize a particular dimension (e.g., determining the set of conditions that would yield most runoff). Not surprisingly, simulations are widely used in many Indian natural resource agencies. Some have been developed locally (e.g., stream flow forecasting at CWPRS), and others have been imported (e.g., the Universal Soil Loss Equation at CSWCRTI). In contrast, optimization models are not in general use. These, however, offer a powerful and essential set of tools for making natural resource management decisions (see section 1.c). For example, fuelwood is a low-value commodity and thus a viable marketing program must seek to minimize transport costs. Knowing where and how much fuelwood is produced, how demand is distributed, and the costs and range of various forms of transportation (headloading, cart, bicycle, truck), an optimization model would seek to locate collection points that would have the lowest net transport costs.

Neither simulations nor optimization models have been implemented within an Indian GIS environment so that specific areas can be targeted for investigation or intervention. We regard both simulation and optimization modeling to be especially critical to developing better resource management, and we suggest that it is an area in which India has capability that has not been fully exploited (e.g., CWPRS, TERI, and SRI).

6. Expert Systems

Expert systems will be defined broadly to include, on the one hand, the collection of software that seeks to solve a limited set of problems (e.g., selection of proper building materials) by capturing the knowledge of an expert (i.e., construction engineer), and the ordering of it in such a way that it can be programmed and installed on a computer. The user is not expected to have any particular skills. On the other hand, and at a less sophisticated level, we also define an expert system as a more limited package of one--or a set of--complex simulations or models that can be employed by a skilled user in a

variety of applications without extensive knowledge of the model itself. For example, CWPRS has developed complex mathematical models of stream flows. Other, often state, agencies are interested in these, but it requires a minimum of two weeks of training for engineers to use them. These might be more widely distributed if a comprehensive user interface were designed that would lead the engineer through the process.

7. Mass Storage System

Optical mass storage systems, such as CD-ROM (compact disk-read-only memory) are devices that permit quick access to large, prerecorded data sets. They require special-purpose, dedicated hardware. If the quality of natural resource research and management is to improve, it is critical for those agencies to have access to bibliographic information. In Europe and North America, this can be done by accessing commercial databases via the telecommunications network. Although attempts are under way to improve telecommunications in India, it is unrealistic to expect significant improvements in the network within the next five years.

Fortunately, major databases that include development topics (e.g., AGRIS, AGRICOLA, and CAB) distribute their collections on CD-ROM on a subscription basis. Installation of these systems at selected information resource nodes will go some distance in providing critical research tools to the appropriate agencies (see section 1.d).

C. Organizational Strengths and Opportunities

This section presents a brief discussion of two general classes of organizations with relevance for RMAT. In the first group we list those organizations, both governmental and non-governmental (NGO), with which we had a chance to discuss RMAT. On the basis of these discussions, we were able to form a preliminary judgment that the organization was interested in one or more dimension of RMAT, and that the organization would be a constructive venue for collaboration. In the second group we list those organizations for which RMAT seems appropriate, but no clear role has yet been determined. Team members were able to visit some, but not all, of the organizations in this group. Subsequent project design efforts will need to ascertain the possible role for these organizations.

The project concept review team agrees that RMAT activities should be implemented by private sector entities where possible. However, due to the short time frame in country and the few private entities from the series of field visits, adequate coverage of private sector entities was not possible. We recommend that subsequent project development efforts focus on

the types of Indian private sector services that could be supplied to carry out RMAT activities.

In general, we propose that all the computer-related support be performed by private firms. There are adequate numbers of firms and trained staff, although some retraining will be required for the new technologies (e.g., expert systems and GIS). Other commercial activities would also be carried out by private firms. For example, we learned that an Indian and a U.S. drip irrigation company have approached USAID/India for assistance in promoting appropriate drip irrigation technologies in India. Cost and pricing questions need to be worked out in detailed design phases. Innovative funding and payback mechanisms such as those used under the AID-funded PACT project should be explored.

We also recommend that all the RMAT activities with PVOs, NGOs, and professional societies be given careful consideration. As most of these are nonprofit operations, a PACT-type mechanism may not work as well. Some technical assistance from U.S. firms or PVOs should be considered as previous programs in this area in other countries have met with some success.

Regarding the public sector agencies recommended to participate in RMAT, a careful analysis should be done of each to determine their capacity to support recommended activities. Future project development efforts should focus on innovative features that would allow recovery of some or all of the costs of project interventions through user fees, sale of publications, or budgetary credits from other government units that use the improved information generated under RMAT support.

The market for service support firms should be explored in relation to public sector needs. As in the United States and many other countries, firms in the information technology, agrotechnology, and technical and management assistance industries supply services to public as well as private clients. For example, "value-added" firms in the GIS industry enhance digital imagery from satellites to supply state and federal governments with targeted information. They also assist large-scale agroindustrial clients in planning production and marketing strategies.

1. Interested in, and Appropriate for, RMAT

a. Private Organizations

(1) Bharatiya Agro-Industries Foundation (BAIF), Pune

BAIF was started several decades ago with a serious commitment to the improvement of rural life in India. Its Gandhian perspective brings it into close contact with the

village poor to determine the needs and aspirations of its clients. It then develops applied research programs that will result in findings of direct relevance to its clients. The foundation has the most successful artificial insemination (AI) program in India. While AI may appear, at first blush, to be somewhat removed from natural resource management, the genetic improvement of livestock may be the single most important contribution to solving the overgrazing problem in India. People too poor to have cows will acquire goats and sheep, with serious results for rangelands. Moreover, improved cattle become too valuable to allow to wander around at will and owners then undertake stall-feeding regimes with salutary results for rangeland.

BAIF has a very successful biomass production program, along with complete recycling of animal waste through biogas plants. It is keen to extend its research findings, through extension programs, to millions of farmers in the southern part of India.

(2) Systems Research Institute (SRI), Pune

SRI is a private, not-for-profit institute that applies systems analysis to public policy problems. Most of its work focuses on issues that affect lower-income populations heavily reliant on natural resources. There are two areas in which they have notable expertise. First, they have developed their own PC-based cartographic information (THEMAPS) and digitizing (DIGITIZ) systems that have been sold to various government agencies. Although more expensive and less powerful than comparable systems in the United States, by developing this system SRI has assembled a good programming staff and gained experience in applying the technology and in training other agencies in its use. Second, its recent work has led to the development of urban energy demand models that have important biomass components. Its participation in the GIS and biomass demand modeling activities is warranted.

(3) Tata Energy Research Institute (TERI), New Delhi

TERI was founded by the Tata firm in 1982 to conduct research on various aspects of energy. It organizes workshops on energy and the environment, conducts research on emissions from chulas and other biomass-burning devices, studies air-quality modeling and the health effects of such emissions, and encourages the use of renewable sources of energy. With a highly qualified staff of 150 and a successful nationwide reputation, it is recognized a one of the leading NGOs in India. Programs involving TERI include biomass marketing and client-oriented decisions for use in extension activities.

b. Governmental Organizations

(1) Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Dehra Dun

CSWCRTI has an extremely well-qualified staff with a number of field research stations around the country. It has done excellent work in water harvesting research and was instrumental in the successful development of the Sukhomajri village soil conservation and water management scheme. It holds promise for applied research in natural resource management, especially that focused on soil and water resources. It has trained over 7,000 individuals and seem interested in collaborating with other agencies to integrate its training with other disciplines--including the social sciences.

(2) Central Water and Power Research Station (CWPRS), Pune

This research station is under the control of the Central Water Commission and performs water-oriented research under contract to governmental organizations in India and abroad. The staff has excellent mathematical modeling capabilities and has begun to promote their skills and abilities. The director (Dr. C. Z. Tarapore) seems interested in collaborative efforts to broaden its traditional base from a rather strict engineering perspective.

(3) Forest Survey of India (FSI), Dehra Dun

FSI is responsible for producing maps of forest resources for all of India. Presently, it relies on manual interpretation of satellite images to monitor forest cover; this work results in the production of maps every two years. A French image-processing system has been installed, and a geographic information system (Canadian?) will be added in the near future in collaboration with Ohio State University. Planning for the transition from manual to automated interpretation and map production does not appear to be proceeding well. The director, Dr. J. B. Lal, directly requested assistance in determining how it should proceed, and also in selecting the tools to be used. We suggest that it take the lead in the forest and farm biomass inventory activity.

(4) Central Water Commission (CWC), New Delhi

CWC is an agency within the Ministry of Water Resources. It is the central counterpart of the state water departments. CWC has responsibility for interstate rivers and canals, and for surface water and groundwater monitoring and management. CWC is concerned with both water supply and flood-control problems within India.

(5) National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Nagpur

This organization, part of the Indian Council of Agricultural Research (ICAR), is primarily concerned with soil mapping throughout India. A major soil resource mapping project was initiated in 1986 and is expected to be completed by 1992. The director, Dr. J. Sehgal, outlined several major new initiatives to be pursued in the near future: the generation of a national database keyed to soil resources; the complete correlation and classification of soils geared to agricultural potential; increased emphasis on soil micro-morphology; and an expanded training course in soil resource mapping, reading and interpreting soil survey maps, and land-use evaluation. The director expressed interest in expanding its work in remote sensing and in GIS methods, and the necessary equipment and software has already been purchased but not installed. He was also confident that it would be the logical unit to collaborate with CSWCRTI on site selection for micro-watershed projects such as Sukhomajri. Like the Forest Survey of India, this organization is at a critical juncture in the move from manual to digital data processing.

(6) Kerala Forest Research Institute (KFRI), Peechi

KFRI was founded in 1975 as an autonomous organization supported by the Kerala state government and contracting its services to state departments elsewhere in India. A variety of research projects in forestry, wildlife management and wood science are under way and the organization has a well-founded reputation for timely and focused research achievements. Work with KFRI would concern forest biomass assessment and monitoring.

(7) Centre for Water Resource Development and Management (CWRDM), Calicut

CWRDM was established by the state government of Kerala to function as a center for advanced research, training, and extension on all aspects of water resource utilization. The center provides technical assistance to Kerala government agencies, to government agencies of other Indian states, and to GOI agencies. CWRDM also has an active education and extension division. Like most natural resource research institutes in India, the bulk of the activities of CWRDM consist of basic research. This subjects it to increasing demands to apply research findings to real-world problems of water management. The difficulty resides in rendering research results applicable, and then transferring the responsibility for application to a suitable organization. We suggest as an activity the construc-

tion of expert systems on the basis of research findings to provide tailor-made recommendations to water management problems.

2. RMAT Role Yet to Be Determined

a. Indian Forest Research Institute (IFRI), Dehra Dun

This institute serves as the national research and training institute under the Ministry of Environment and Forests. Virtually all foresters at every level are trained, to some degree, by IFRI. Beyond traditional silviculture and wood technology, IFRI is concentrating on "ecological" management of forests, efficient use of fuelwood, and management of the grassland (range) resource. Although it has little in-house capability, the director, Dr. J. B. Lal, has interests in collaboration, particularly in the areas of fuelwood and range management. Given its pivotal role in shaping forest management attitudes across India, a training role should be defined for it in the forest biomass assessment project.

b. Ministry of Environment and Forests (MEF), New Delhi

At the policy level, much of MEF's attention is currently focused on afforestation of degraded lands that will be a major element in the eighth five-year plan for which they have primary responsibility. Several topics stem from this task that relate to information technologies--particularly in terms of survey--in which MEF requests assistance: biomass inventory on non-forest lands, establishment of multistage sampling scheme at the national level, and implementation of GIS for managing data. At the operational level, there are several areas of concern for MEF including grazing in forests, site selection for major plantings, staff training, improvement of tree breeding and establishment, and selection criteria for multiple-use tree species. MEF has substantial programmatic interests in each of the three major areas of interest defined in RMAT. Its participation and support through IFRI and FSI seems critical to RMAT success.

c. Indian Institute of Forest Management (IIFM), Bhopal

The IIFM was established about 1980 to augment the excellent training in forestry at Dehra Dun. The emphasis at IIFM is on the human dimensions of forest management, and it is said it will be responsible for training many of the foresters moving in a policy-oriented direction. It is also designed to supply graduates to the private sector so skills taught are directly applied in private sector production activities.

d. Institute of Rural Management (IRMA), Anand

The staff of IRMA, primarily economists although including sociologists and lawyers, is young, well-trained, and committed to a research and teaching program focused on natural resource and agricultural problems of rural India. While we did not visit IRMA, one team member has visited IRMA and has worked with the faculty on problems in natural resource economics. The competence of this group could be put to good use in activities associated with RMAT.

e. Indian Institute of Management (IIM), Ahmedabad

Like IRMA, IIM is dedicated to enhancing the level of teaching and research in the social sciences in India--with particular reference to agriculture and natural resources. The staff, somewhat better known than those at IRMA, has a distinguished record of work in areas pertinent to RMAT.

f. Ministry of Science and Technology (MS&T), New Delhi

The team met with several individuals from the Ministry of Science and Technology but we obtained very little indication of their interests in RMAT. The new government is still developing its science and technology initiatives and, while tentatively interested, the ministry was not in a position at this time to make any program commitments.

g. National Institute of Hydrology (NIH)

The team was unable to visit with staff of NIH but this agency would seem appropriate for certain activities concerned with water resource programming.

h. Central Groundwater Board (CGB)

CGB has responsibility for monitoring groundwater levels in India and, while we were unable to visit with CGB staff, it is apparent that a fully developed program to foster the optimal conjunctive use of surface water and groundwater will entail collaboration with this agency.

i. National Informatics Center (NIC)

NIC was mentioned frequently as an important player in information technologies. There soon will be a national network (NICNET) that may be an important ingredient in RMAT. NICNET claims to be the world's largest computer data network, soon covering all 438 administrative districts in India. Plans call for eventual expansion to over 6,000 blocks--a yet smaller administrative unit in the Indian structure. Every block

development officer will then have a personal computer and a small solar-powered satellite receiving station.

j. Computer Maintenance Corporation

This government organization runs INDONET, which is a public network available to the private sector by subscription. A number of private companies are currently subscribing to INDONET.

k. National Institute of Information Technology

This organization is India's largest computer training and consultancy organization, currently doing approximately Rs 168 million ($10 million) worth of business over the past 18 months.

l. Indian Space Research Organization

The space agency, recognizing the "imperative need to adopt a comprehensive approach to the management of natural resources by an optimal mix of modern remote sensing techniques and conventional methods," has established the National Natural Resources Management System (NNRMS). This agency will integrate data obtained through remote sensing into the existing system with "appropriate technical, managerial, and organizational linkages." The Department of Space will be responsible for establishing NNRMS in collaboration with natural resource agencies at both the national and state levels.

SECTION IV

RMAT ACTIVITY PRIORITIES AND PHASING

A. Phase One Activities

Forest Biomass Monitoring and Assessment (1a)

Farm-Based Biomass Monitoring and Assessment (1b)

Farm-Based Soil Conservation (2a)

Catchment Area Soil Conservation (2b)

Data and Information for Decision Support (3c)

Inventory and Dissemination of Current Practices (4a)

Technical Support for Environmental NGOs (4c)

Professional Society Support (4d)

B. Phase Two Activities

Biomass Processing and Marketing (1c)

Information Dissemination (1d)

Information Technologies for Soil Conservation (2c)

Support for Micro-Design in Water Resources (3a)

Interdisciplinary Training for Engineers (4b)

C. Phase Three Activities

Support for Macro-Design in Water Resources (3b)

As mentioned in the beginning of this report, there was insufficient time to develop a detailed plan to move from phases one through three. We recommend that subsequent project development efforts focus on programming the activities in each of the phases so that each phase results in either a finished product or a foundation upon which the subsequent phase will

depend. A major advantage to designing a phased program of assistance will allow maximum flexibility in redirection of resources to those activities that are working while keeping documentation and management requirements to a minimum.

TABLE 1. AGENCIES, TECHNOLOGIES, AND ACTIVITIES

	productivity tools	data acquisition	database management	GIS	systems analysis	expert systems	mass storage
CSWCRTI			2a	2b	2b;2c	2c	2a
CWPRS		3c			3b		3c
FSI		1a;1b		1a;1b	1a;1b		1d
CWC	3a	3c			3a		3c
NBSSLUP					2c	2c	
KFRI	1a	1a;3c				3c	
CWRDM	3b	3c	4a		3b	3c;4a	
BAIF				1b;1c	1b;1c		1d
SRI				1a			
TERI					1a;1c		

KEY TO ACTIVITIES:

1a. Forest Biomass Monitoring and Assessment
1b. Farm-Based Biomass Inventory and Monitoring
1c. Biomass Processing and Marketing
1d. Natural Resource Information Dissemination

2a. Farm-Based Soil Conservation
2b. Catchment Area Management
2c. Information Technologies for Soil Conservation Site Selection

3a. Decision-Support Systems for Micro-system Design and Management
3b. Decision-Support Systems for Macro-system Design and Management
3c. Data and Information for Micro- and Macro-system Decision Support

4a. Inventory and Dissemination of Current Practices
4b. Interdisciplinary Training for Water Engineers
4c. Technical Training for Environmental NGOs and PVOs
4d. Professional Society Support

INDIA RMAT LOGFRAME

Project Number: 386-0520

Narrative Summary (NS)	Measureable Indicators (OVI)	Means of Verification (MOV)	Important Assumptions
Goal: 1 To accelerate India's economic growth through a more efficient and sustainable management of natural resources.	1.1 Economic growth rate Quality of life indicators Forest protection Improved agricultural production	1.1 Data on economic growth, forested area, afforestation, irrigated agricultural output	(goal to supergoal) 1.1 Better natural resource management is essential to economic growth. Current trends in natural resource supply and demand continue.
Purpose: 1 To strengthen the ability of private and public enterprises to generate and analyze information in the design and implementation of sustainable economic development and natural resource investments.	1.1 Biomass assessment and monitoring capability established Capabilities of farmers and soil management advisors (foresters, extension agents) strengthened Capabilities of water resource planners and managers strengthened	1.1 Assessments of financial and transactional cost savings and benefits in cases of actual application	(purpose to goal) 1.1 Better information results in better natural resource management. Training in information technologies improves natural resource management capability. Information management policies are consistent with information management technologies.
Outputs: 1 More accurate, timely, and inexpensive data are collected and used in a wide variety of field problem-solving situations concerning: (1) biomass assessment and monitoring; (2) soil erosion control; and (3) water resources management.	1.1 Client-oriented automated hydrometeorological data collection systems, and multistage biomass remote-sensing monitoring systems in place	1.1 Tracking of products developed, requested and delivered, and number of systems replicated	(output to purpose) 1.1 Better natural resource data collection, analysis, and dissemination yield better information. Client-defined information products are most likely to be used. Appropriate technical support is available. Financial support is provided at the levels and time planned.
2 Data analysis capacity is broadened and strengthened for specific problem solving in economically critical areas regarding biomass assessment and monitoring, soil erosion control, and water resources management.	2.1 Local water management database assembled.	2.1 Evaluating selected field applications	2.1 Appropriate individuals receive training and remain in-post for three years.
3 Data and information are disseminated to a broad spectrum of client groups concerned with biomass, soil erosion, and water resources.	3.1 Productivity tools, GIS, models, and expert systems developed and installed. 3.2 Database management systems, mass storage systems, and information exchange networks established and professional societies strengthened.	3.1 Monitoring of client use	3.1 Mail service will remain more reliable than telecommunications for electronic data transfer.

INDIA RMAT LOGFRAME (cont'd)

Project Number: 386-0520

ivities:	Inputs/Resources:		(activity to output)
Hardware	microcomputers CD-ROM devices automated instrumentation spreadsheets CADD programs expert systems bibliographies statistical programs simulation programs river basin models WEPP display graphics GIS intensive courses field projects extension programs	1.1	1.1 Upgraded hardware, software, training, and research support groups yield better data collection, analysis, and dissemination Hardware manufacturers and software suppliers provide and maintain needed equipment and programs. Finances available to upgrade hardware and software and for training.
Software	linkage of professional societies	2.1 Programs developed and installed in agencies Results of programs effective in management	2.1 Clients are involved in software development and information product design.
Training		3.1 Courses held Field projects established	3.1
Professional societies		4.1 Professional linkages in place	4.1

PCLogFRAME (C) 1988 Team Technologies, Inc.

BEST AVAILABLE COPY

REFERENCES

Agency for International Development. Country Development Strategy Statement, FY 1990. Washington: June 1988.

Allibard, Terry. Catalyst of Development: Voluntary Agencies in India. West Hartford: Kumarian Press, 1983.

Bellis, James M. "Client-Oriented Decision Support Systems for USAID's Indian Natural Resource Management Activities." Consultant's report to USAID/India. New Delhi: November 1989.

Bromley, Daniel W. "Improving Irrigated Agriculture: Institutional Reform and the Small Farmer." World Bank Staff Working Paper 531. Washington: World Bank, 1982.

Chambers, Robert, N. C. Saxena, and Tushaar Shah. To the Hands of the Poor: Water and Trees. New Delhi: Oxford and IBH Publishing Co., 1989.

Daines, Samuel R. and J. R. Pawar, "Economic Returns to Irrigation in India," USAID/India. New Delhi: April 1987.

Government of India (GOI). "Timber Trends and Prospects in India." Mimeo. New Delhi: Ministry of Food and Agriculture, 1962.

Gregersen, Hans, Sydney Draper, and Dieter Elz. "From People and Trees." Washington: World Bank, Economic Development Institute, Seminar Series, 1989.

Grewal, S. S., S. P. Mittal, Y. Agnihotri, and L. N. Dubey. "Rainwater Harvesting for the Management of Agricultural Droughts in the Foothills of Northern India." Agricultural Water Management 16:309-22 (1989).

Jodha, N. S. "Common Property Resources and Rural Poor in Dry Regions of India." Economic and Political Weekly 21:1169-81 (July 5, 1986).

Leach, Gerald. Household Energy in South Asia. London: International Institute for Environment and Development, 1987.

Panayotou, Theodore. "Natural Resources and the Environment in the Economies of Asia and The Near East." Paper prepared for the World Resources Institute. Washington: July 1989.

Previous Page Blank

Repetto, Robert, William Magrath, Michael Wells, Christine Beer, and Fabrizio Rossini. "Wasting Assets: Natural Resources in the National Income Accounts." Washington: World Resources Institute, 1989.

Singh, Shekhar. "Some Aspects of the Ecological Crisis in India." Social Scientist 13:82-89 (1985).

TAC (Technology Application Center, University of New Mexico). "Modalities for Stimulating Development and Transfer of Science and Technology Applied to Resource Planning and Management in India." Contractor report to USAID. March 1989.

United Nations Development Programme. "India: Meeting Basic Energy Needs of the Poor." New Delhi: UNDP and ESCAP, 1986.

USAID/India. "USAID/India's Irrigation/Water Resources Assistance Program." New Delhi: USAID/India, Office of Irrigation, Water Resources, October 22, 1987.

USAID/India. "A New Strategy for A.I.D. in India's Agricultural Sector." New Delhi: USAID, November 29, 1988.

World Resources Institute. World Resources, 1988-89. Washington: 1988.

World Bank. World Development Report 1989." Washington: 1989.