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DEVELOPMENT OF SOLUTIONS MANUAL

Prepared by
Water Management Research Project Staff

Water Management
Technical Report No. 65C

Development Process for Improving Irrigation Water Management on Farms

DEVELOPMENT OF SOLUTIONS MANUAL

WATER MANAGEMENT TECHNICAL REPORT NO. 65C

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April 1980

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CHAPTER I

INTRODUCTION

RESEARCH AND DEVELOPMENT PROCESS

This is the second in a series of three manuals designed as practical guides to research, development, and transfer of technology in agricultural water management. The purpose of this volume is to explain how solutions to problems are developed. Because there is considerable overlap between the three manuals, it is useful to outline how the "Development of Solutions" relates to the other two volumes.

Together, the manuals describe three phases that comprise an entire research and development process. In the Problem Identification phase, the research and development staff (also referred to in this manual as the program team, program staff, or team) seeks to understand the agricultural system as it exists. In the "Development of Solutions" phase alternative designs for the system are identified and evaluated. In the Project Implementation phase the program staff attempts to change the present system to a better one. Described in this manner, the phases seem distinct. In reality, however, they usually overlap because information is never complete from any particular phase. This results in continuous recycling through earlier phases as new facts reveal a need for further information. For example, in the process of developing solutions, researchers discover new facts about farmer management practices. These new facts may necessitate redefinition of the problem and reordering of the associated priorities. Thus, it is likely that problem definitions will continue to change as solutions evolve and are implemented. When one constraint is relaxed in a production system, other constraints will become critical. Because implementation occurs on a larger scale than the development of solutions, it is likely that unforeseen constraints will emerge. This requires that solutions be flexible enough to be adapted to unexpected problems. Such flexibility involves a refinement in the development of solutions and the appearance of these unforeseen problems provides additional knowledge about problem identification.

Although the research and development process is a continuous recycling through phases, the manuals are organized in a separate and sequential format. Hopefully, by allocating specific blocks of time and effort to each phase program members will be encouraged to recognize the limits of program resources and to keep sight of the goals they must reach.

INTERDISCIPLINARY APPROACH

Generally, the research and development staff hopes to suggest and encourage changes that will serve the farmers' interest. However, the implications of change do not always stop with individual farmers. Widespread changes affecting farmers commonly spread throughout the area which facilitates implementation. The evaluation of widespread changes requires that the research and development staff gain a thorough understanding of how the farm components are integrated. This understanding is difficult to achieve since the individuals have been trained to concentrate their methods of investigation on their discipline, ignoring factors relegated to other disciplines. Therefore, achievement of an interdisciplinary perspective requires special effort, especially by project managers.

When the interdisciplinary approach is required it should be established at the beginning of the project. Specific steps necessary to facilitate its effective operation are described below.

1. All staff should participate in important decisions about the project so that solutions will be based on several perspectives. When all members participate, they tend to feel responsible for the decisions and are more committed to their support.

2. An important part of decision making is the setting of realistic goals by group members. It should be clear that goal achievement will be used by the manager to measure individual and group performance.

3. A systematic feedback network should be developed to evaluate performance relative to the goals. Feedback between staff as well as between staff and the program manager are essential to interdisciplinary projects. Members working on different parts of a problem should periodically share information about the direction, progress, and significant interrelationships of the work.

4. Methods should be developed for handling internal conflicts. Relaxed and objective staff sessions should be held in which existing or potential conflicts are recognized and means of resolution are arranged. Ignoring conflict generally makes it more intense and the staff tends to work against each other.

A detailed discussion of how to accomplish these steps is offered in the Project Implementation manual.

CLIENT INVOLVEMENT

Client involvement is an effective method for gaining information about the dynamics of the farm system and of identifying sources of support or obstacles to change. Farmers generally have extensive relevant information as well as an intuitive understanding of how their system works; yet, they are often ignored by outside experts. The tendency for staff to discount farmer input is most acute in the Development of Solutions phase. In the Problem Identification phase the farmers must at least be studied to determine the problems; and in the Project Implementation phase they must at least be told how to solve those problems. However, in the Development of Solutions phase they are often considered part of the problem and, therefore, are not expected to know about the solutions. In the approach advocated by this manual, the farmer is regarded as an important source of ideas for potential solutions that experts may overlook. Furthermore, because of their innate "interdisciplinary" familiarity with their system, the farmers can assist the program in understanding the system's dynamics and in anticipating consequences of proposed changes. Client involvement and an interdisciplinary approach are recurring, interconnected themes or "key concepts" in all three manuals.

CONCEPTUAL FRAMEWORK

The transition from the Problem Identification phase to the Development of Solutions phase occurs when the staff agrees to change emphasis from understanding problems to actual attempts at solution. Development of solutions is characterized by 1) identification and ranking of plausible alternatives, 2) detailed development of solutions to priority problems, and 3) assessment, refinement, and assembling the solutions.

These steps are elaborated in Chapters II, III, and IV, respectively, and are represented in the flow chart in Figure 1. It will be useful for the reader to refer to the flow chart while reading the following summary.

When the problem identification staff arrives, they generally possess defined objectives and constraints, and a limited understanding of the farm system they will confront. At the start of the Development of Solutions phase, objectives have been refined, constraints have been translated to operational limitations, and there is a partial understanding of the causality behind the more important problems.

In some cases, solutions to problems may naturally evolve even before the end of the Problem Identification phase. For example, farmers may suffer from a problem in water supply scheduling that they cannot change due to the lack of access to officials. The problem identification staff may provide the necessary contacts to reach a fast solution. Most problems are more difficult, having multiple, interrelated causes, and the development of effective solutions requires planning, field trials, evaluation, and refinement. These stages are covered in this manual.

Faced with a situation where solutions are not obvious, a worthwhile technique to elicit ideas is a "brainstorming session." All members of the group are encouraged to spontaneously submit ideas with no threat of judgment. Inputs from farmers can be included indirectly through the members. After many ideas have been contributed to each problem, they are evaluated with respect to program objectives and constraints to eliminate the impractical or implausible solutions.

Plausible solutions are then classified against several important criteria such as effects on various groups, disciplines involved, resources required from various sources, time requirements, uncertainty, and complementarities with other solutions. It is useful to jointly display solutions and criteria in a solution/criteria matrix that gives information about the appropriateness of each plausible solution. This facilitates comparison of solutions and identification of information needed to properly evaluate the alternatives.

DEVELOPMENT OF SOLUTIONS

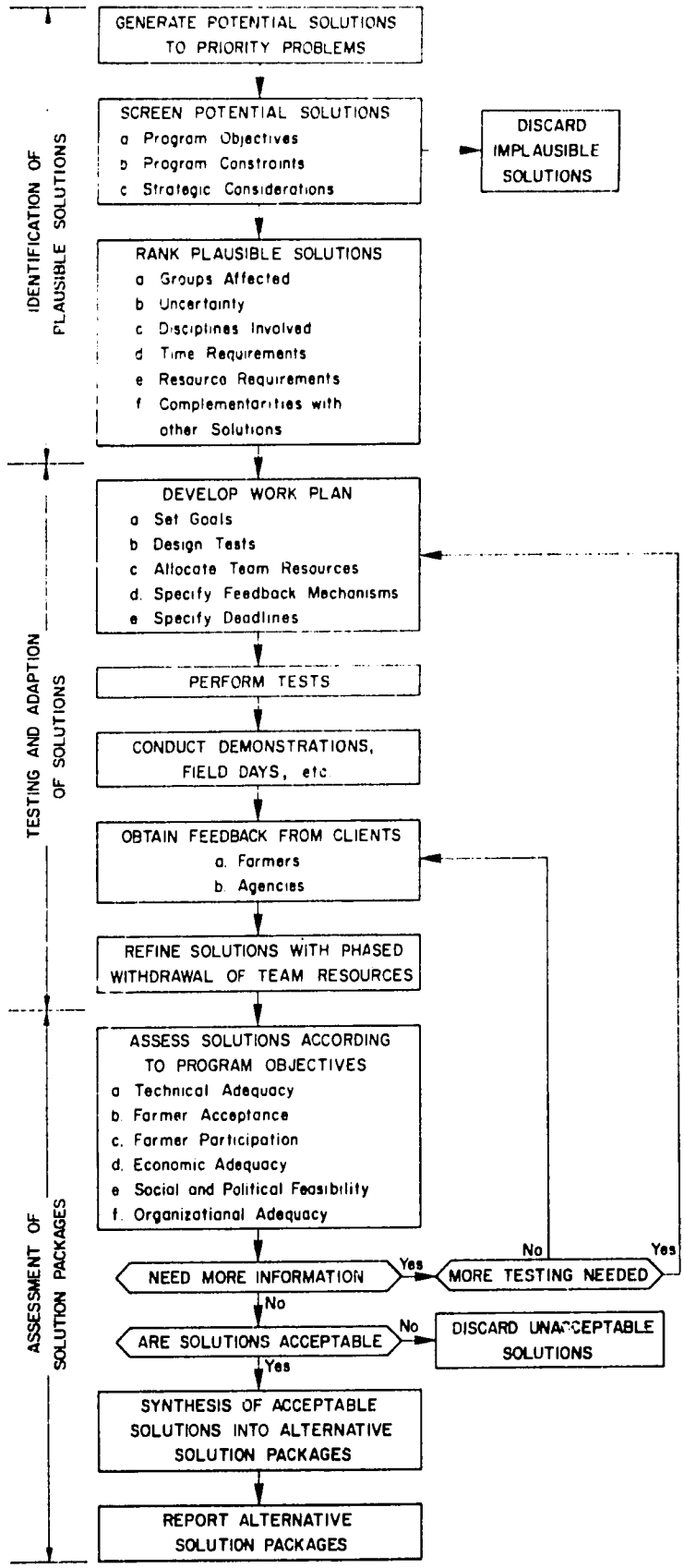

Figure 1. Flow diagram for the Development of Solutions phase in the development process for improving irrigation water management on farms.

Identification of groups affected by each solution precludes a more detailed consideration of the objectives of the group as related to the solution. These objectives are applied in a valuation of each solution from different viewpoints. Program objectives are again refined to reflect what was learned about farmers' interests and then used to help rank the plausible solutions. Finally, high ranking solutions are chosen for development.

Detailed development of solutions begins with identification of information required to judge feasibility and adequacy of each one. This process should involve interdisciplinary subgroups who are assigned to outline the description and schedule of tests or trials they expect to conduct. Periodic checks and coordination meetings should be held to insure that progress is correctly directed and that information will be available when needed by other subgroups and project implementation personnel (see Project Implementation manual).

When sufficient information is available on the solutions, the staff should meet again to design combinations of solutions which are designated as "packages." These combinations are evaluated and refined in field trials until their benefits are clearly perceivable. In successive trials, government inputs to the program are replaced by farmer inputs until farmers take as much responsibility as seems practical and the level of inputs required from the government or some other off-farm source could be provided in a broad-scale implementation project.

As field trials progress, it is important to maintain communication with concerned government agencies. This will avoid costly misdirection of effort resulting from a lack of understanding of government objectives. It will also facilitate institutionalizing some of the solutions by having them become a part of the normal activities of the farming community.

When field tests are finished, the solutions are given a final, thorough assessment for technical adequacy, farmer acceptance, farmer participation, economic adequacy, social and political feasibility, and organizational adequacy. The last step in solution development is to redesign the alternatives for widespread dissemination and formal reporting of the alternative solution packages for distribution to involved agencies.

CHAPTER II

IDENTIFICATION OF PLAUSIBLE SOLUTIONS

Strategy is inherent in the approach advocated by these manuals, but nowhere is strategy more central than in selecting a set of plausible solutions for development (Figure 2). This chapter suggests ways to form strategies consistent with program objectives and constraints. Certain criteria are discussed as they relate to planning research and development, and potential sources of ideas and technology are listed.

As with other phases, a team approach and client involvement are important, and their importance in strategy formation cannot be overemphasized. Team members and clients become motivated and self-directed if they are actively involved in the formation of strategies. Furthermore, farmers and other clients who work closely with team members can become important sources of information regarding the system. The team manager may be anxious to progress with what seems like obviously productive tasks, but time spent involving staff and clients in strategic planning will help mobilize initiative and establish communication channels through which reliable information can be obtained.

RESOURCES AND PRIORITIES FOR THE DEVELOPMENT PROCESS

Initial statements of program objectives and limits come from outside the program, presumably from a government agency. However, statements of these guidelines are rarely precise and usually require refinement before they can be used. This is advantageous in that a team often has flexibility in defining its own priorities, but it can be a liability since there may be objectives and constraints which are unstated, but important. Consequently, program leaders must assume responsibility for interacting with government officials to discover any such objectives and constraints. Once there is reasonable confidence that the team understands what is expected by its sponsor(s), it can begin a process of elimination to narrow the set of alternatives it will consider for development. Although this should have been done in the Problem Identification phase, it is reiterated here because of the importance of specifically defining program objectives in order to proceed positively in the Development of Solutions phase.

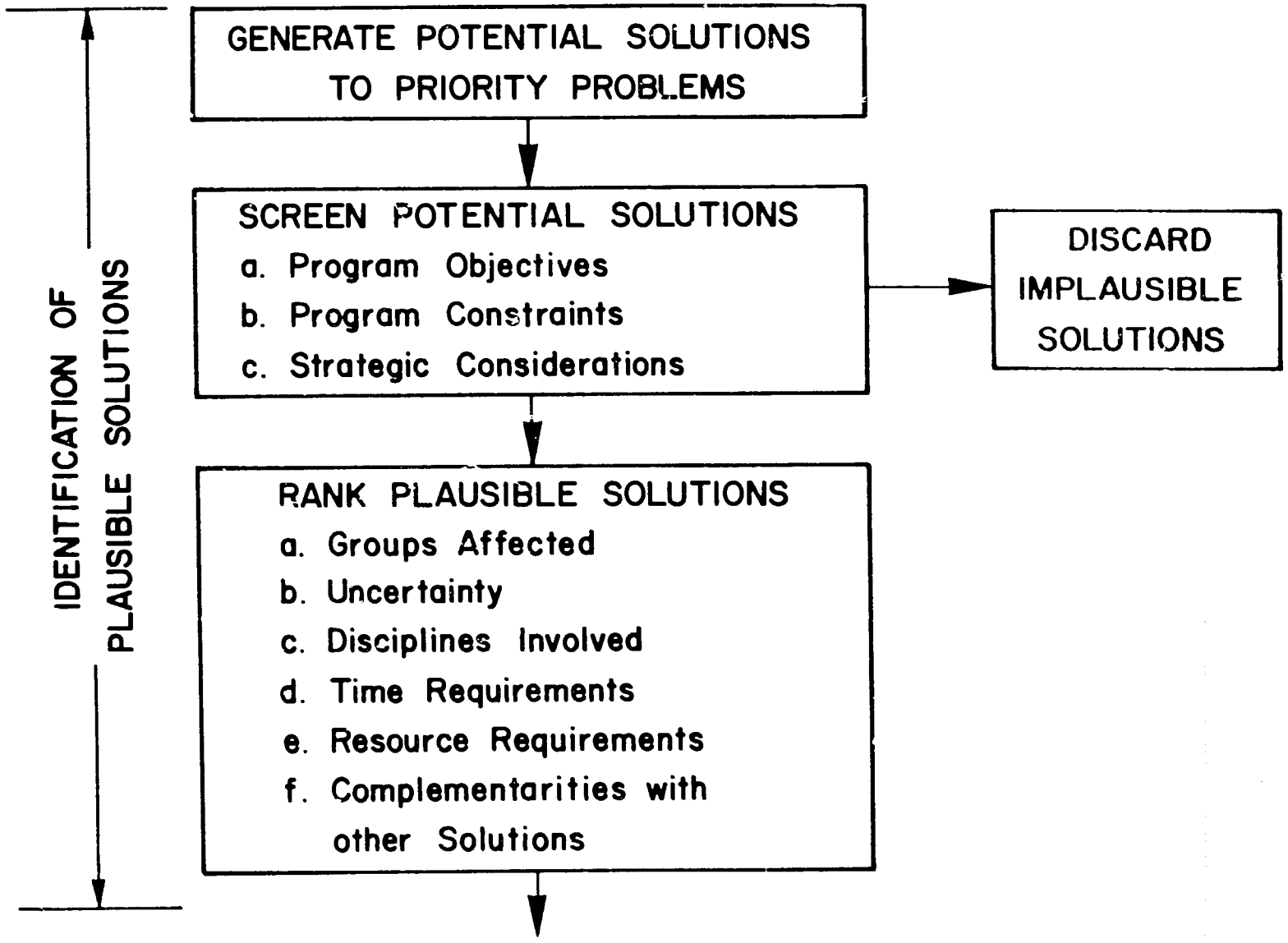

Figure 2. Flow diagram for the Identification of Plausible Solutions subphase of the Development of Solutions phase.

Defining Available Resources

Many of the resources available for the solution development phase are explicit from the start such as time allotted to research and development; budgets of capital, manpower, and facilities; and authority of program leaders to obtain cooperation from government agencies. The development of solutions may also be facilitated or constrained by organizational, institutional, or legal factors. Depending upon the political situation and seriousness of the problems that suggested solutions solve or create, such "institutional" factors may be subject to change. Examples of change that may occur are government policies regarding taxes, subsidies, and price controls on agriculture; minimum wages; laws restricting size or tenure of landholdings; scarcity of foreign exchange; limited primary commodities such as cement and fertilizer; and incentive systems in government agencies.

Resources available for the Project Implementation phase are generally uncertain. Time and budget allocated to project implementation depends upon the urgency and importance of the problems as well as the effectiveness of the solutions developed. Consequently, the resources available for implementation are uncertain. The organizational, institutional, and legal resource constraints are less predictable for implementation than for research and development. For instance, farmers participating enthusiastically in an initial program may even convince visiting government officials that new organizations, institutions, and laws should be formulated to facilitate the implementation phase of the program.

In spite of uncertainties, staff should be aware of potential resources available for implementation and recognize their limitations. A good way to coordinate this approach is to hold a meeting in which resources are listed and matched against problems they may help solve. It would be useful to display this information on a blackboard or other large surface to allow all members to participate. Resources available will generally be more limited during the Project Implementation phase than during the Development of Solutions phase. Research and development programs are often devised outside of established government agencies. However, implementation is often allocated to these existing agencies. Unfortunately, these agencies have less access to the type of

resources required for further adaptation of the solution. Consequently, the testing and adaptation of solutions to be done in the Development of Solutions phase must take into consideration the resources that will likely be available in the Project Implementation phase.

Examples of Constraints

An example of how program resources might be arranged so that priority problems and their solutions can be matched is shown in Table 1. Resources listed are examples of categories that could be applicable in on-farm water management.

The last major category in Table 1 is "Information." Research in the Development of Solutions phase will increase the available information. However, many times information from other sources will have to be substituted because of time limitations. By reviewing the checklist, information that might be overlooked may be incorporated in the assessment of the project requirements. The categories listed are general and could be further detailed. At the end of the list of information is "Information regarding interest groups." This includes sociological and economic aspects that are crucial in developing both research and implementation strategies. Interest groups exist formally and informally in all areas of society. For instance, local watercourse associations serve different groups of farmers with opposing interests; various government agencies have interagency priorities; and ministries (e.g., Irrigation and Agriculture) have diverse viewpoints.

Defining Priorities

If the sequence presented in the Problem Identification manual has been followed, there is already a well-defined set of objectives and priorities. It is imperative that staff members share an understanding of the general program objectives and that more specific operational objectives, which will emerge as plausible solutions, are identified.

One way to define priorities is to list the general program objectives first. The general objectives, as cited in the Problem Identification manual are: (1) Increased Agricultural Production; (2) Increased Equity of Income Distribution; and (3) Resource Conservation. It is possible that a program will have a narrowly

Table 1. Program Resources Checklist

Project Personnel

- Agronomists
- Engineers
  - Civil
  - Agricultural
- Hydrologists
- Economists
- Sociologists/Anthropologists
- Lawyers
- Managers

Research and Development Budget

- Transportation
- Clerical
- Computational
- Laboratory equipment
- Field equipment
- Field assistants

Equipment

- Water supply data
- Lab equipment
- Field testing equipment
- Tractors
- Earthmovers
- Levelers
- Computer

Access to Agencies Resources

- Personnel
  - Agronomists, etc.
- Facilities
  - Laboratories
  - Experiment station
  - Field equipment

Access to Authority

Irrigation Department
- National
- Regional
- Local

Ministry of Agriculture
- National
- Regional
- Local

Ministry of Transportation
- National
- Regional
- Local

Ministry of Finance
- National
- Regional
- Local

Information (local, regional, national, and/or international)

- Climatic data
- Soil data
- Water supply data
- Hydrologic data
- Plant varieties and properties
- Data on plant disease and pests
- Economic data
- Socio-cultural data
- Policy data
- Information regarding interest groups

defined objective that fits under one of the above general objectives, probably under "Increasing Agricultural Production." However, the nature of on-farm water management projects is such that solutions generally involve all three objectives. These specific program objectives can be determined by detailing the general objective. An example of how this might be accomplished is shown in Table 2.

As with the constraint list of Table 1, objectives in Table 2 give general examples of what should be considered. Operational objectives of an on-farm water management development program will have more detail. Furthermore, many of the objectives listed will initially be outside the domain of most on-farm water management development projects. Nevertheless, such situations are sometimes the unintended result of development programs and should be considered as potential by-products of solutions.

As solutions are identified they can be defined in terms of specific activities such as the "design and construction of watercourse lining, costing no more than $2 per foot (annualized), designed to carry up to 3 ft^3 of water per second with delivery efficiency of 99 percent per 1,000 feet." These goals can be related back to program objectives:

> Water is saved thereby increasing acres that can be irrigated resulting in an increase in farmer incomes.
>
> Deep percolation which causes loss of land resources to waterlogging is reduced.
>
> Finally, farmers at the ends of watercourses benefit relatively more than those at the beginning which leads to a more equitable distribution of wealth.

This example shows how goals are expressed in terms of measurable performance criteria; and therefore, the "operational objectives" mentioned at the beginning of the chapter.

Table 2. Examples of program objectives.

Increasing Crop Production

--Optimizing Use of Plant Environment
- Identification of best crops and varieties for environment
- Breeding new varieties
- Improving practices

--Complementing Plant Environment
- Reduce costs of agri-chemicals
- Add organic matter to soil
- Add tillable acreage by modifying terrain

--Optimizing Labor Use
- Change cropping patterns to reduce labor bottlenecks
- Education of farmers
- Improved nutrition
- Improved health

--Complementing Labor Use
- Introduction of labor-saving machines
- Facilitate mobility of seasonal laborers

--Optimizing Use of Current Water Supply and Removal System
- Land leveling
- Use of bunds
- Maintenance of delivery and removal systems
- Improved application efficiency
- Improvement of scheduling

--Complementing Water Supply and Removal System
- Modification of supply and removal systems
- Addition of storage capacity
- Addition of wells

--Optimizing Use of Current Organizational, Institutional, and Legal Infrastructure
- Rationalization of prices with national priorities
- Rationalization of organizational incentive structures
- Develop incentives for Water Users' Associations
- Education and training of agency staff

--Changing Existing Infrastructure
- Add new organizations to service farmers
- Development of marketing services for inputs and outputs
- Develop new organization to manage interregional water allocation
- Change laws to allocate water rights to individuals
- Land consolidation
- Land reform
- Organize cooperatives or Water Users' Associations

Table 2. Examples of program objectives (continued).

Income Distribution

--Increase Productivity of Resources Belonging to Poorer Farmers and Laborers

Labor :	Education, extension, nutrition, health, machinery, chemical inputs, new crop varieties with shorter duration
Land :	Consolidation, leveling, increased water supply, complementing nutrients, higher yielding crop varieties
Water:	Increase application efficiency, increase delivery efficiency, introduce crop varieties better adapted to water

--Increase Access to Productive Resources

Land :	Reform, consolidate and cooperative use
Water :	Redistribution and enforcement of water rights
Capital :	Credit, collective ownership, indivisible capital equipment (tubewells, tractors)
Information:	Extension, education, mass media

--Direct Redistribution of Income
- Tax relief
- Subsidies
- Food programs
- Free medical care
- Direct transfer payments (social security, welfare)

--Increase Demand for Farm Products
- Transportation, storage, and other marketing systems
- Development of overseas markets
- Development of domestic processing industries

--Reduce Uncertainty for Smaller Farmers
- Disease and pest control
- Regulation of water supply
- Regulation of prices
- Crop insurance
- Organize credit cooperatives
- Establish dependable marketing for inputs and outputs

--Increase Access of Small Farmers to Government Agencies
- Organize small farmers into politically-effective groups
- Furnish small farmers with advocates to plead cases with agencies

Table 2. Examples of program objectives (continued).

Resource Conservation
--Water
Maintenance of quality of water supplies
Maintenance of sustainable yield from water supplies
Increasing sustainable yields through storage
--Soil
Prevention of soil erosion
Reclamation of degraded soils
Maintenance of acceptable levels of soil salinity
--Air
Maintain safe quality
Maintain aesthetic qualtiy
--Forests
Maintenance of sustainable yields from forests
Extend acreage of forests to increase sustainable yields
Introduce substitutes for wood as fuel and construction materials
--Fisheries
Maintenance of quality of water
Maintenance of sustainable yields
Increasing sustainable yields
--Rangeland
Maintain sustainable yield
Increase nutritional value of yield
Increase efficiency of animals

Strategic Considerations

Having acknowledged both constraints and objectives, the team can, without regarding specific solutions, anticipate certain strategic considerations that will affect the types of solutions selected for development.

Temporary Versus Permanent Change

Often political realities necessitate immediate results from certain projects. The program staff may have broadly defined objectives but are expected to show quick results. In this case, a two-stage strategy may be appropriate. Temporary solutions that can be developed and implemented quickly can be utilized while research is done to find permanent answers. For example, a strategy might be to implement a short-term solution to a salinity problem by growing some salt-tolerant crops while developing and evaluating long-term solutions involving alternatives for lowering the water table and removing the salt. In another example, insecticides applied by government agencies can be a temporary solution while insect-tolerant crops are developed or while a cheaper method of control is developed.

A two-stage strategy has the advantage of satisfying the impatience of sponsoring agencies for results while lending credibility to the staff for continuing their work. Restraint, however, must be exercised in use of temporary solutions. For example, a poor choice of an insecticide may result in killing beneficial insects such as honeybees upon which farmers depend for pollination.

Another danger is that farmers may depend too heavily on a temporary solution so that it is difficult to replace with a superior one. For instance, subsidized power for tubewells may stimulate the use of ground water as a temporary solution for water shortages while more effective methods of water application are developed. But temporary subsidies tend to become expected, and if farmers are subsequently asked to invest capital and labor in more efficient water application systems they may resist.

Distortions of market values and conflicts of interest between farmers and the government are inherent in subsidies. Probable effects of these distortions and conflicts should be carefully evaluated when

subsidies are considered as part of the solution. Using subsidies to "bribe" farmers into rapid acceptance of a program is generally inferior to educating the farmers about the merits of the program. If the subsidy program becomes formalized and is widely publicized in an implementation program, it is difficult to reduce the subsidies and obtain continued participation by the farmers. When using subsidies for short-term solutions, publicity about them should be limited and the alternative solution field trials should be sufficiently separated by distance so farmer-participants are not comparing what they are receiving with other alternatives.

Development Costs Versus Implementation Costs

A difference exists between (a) changing the amount, properties, or means of delivery of a given input available to the farmer, and (b) changing the technique in which inputs are combined by the farmer.

Examples of changing the means of delivery are the introduction of new seed varieties, chemical fertilizers, tubewells, and tractors. Use of one of these factors does not necessarily imply changing any other practices. For example, farmers can easily adapt to seedbed preparation done by tractor as well as that done by hand, or to water supplied by a tubewell as opposed to that supplied by a surface water system.

Examples of changing techniques of combining resources are a switch from basin irrigation to furrow irrigation, a switch from uncontrolled flood irrigation to utilization of a bund and controlled paddy irrigation, or a change from dependence on an outside agency for water supply and regulation to a water users' association that maintains and regulates use of local watercourses. Generally, changes of this sort are not standardized and require that farmers adapt the new technique to their circumstances. This implies an increased understanding that is not required for changes of the means of delivery.

Changes in the delivery method generally require adaptation before implementation. Seed varieties, pesticides, fertilizers, and power equipment may require adaptation to local conditions. In addition, they may require elaborate organizations outside the farm or village to support their use.

However, changes in technique leave part of the adaptation, the development, to the farmer(s). This has implications for time and money requirements for development relative to time and money requirements for implementation: changes in mode of delivery generally require more careful research and development but they are readily adopted by farmers, while for changes in technique the reverse is true. Consequently, if solutions that can be quickly implemented are desired it is best to use changes in mode of delivery which are easily adapted to local conditions. This generally excludes comprehensive changes in husbandry techniques and new crop varieties bred in different climates, or machinery for which there is no supporting marketing and service network.

Centralized Versus Local Control

There is another trade-off closely related to that between changes of delivery method and changes in technique which is the trade-off between centralized control and local control of resource allocation. Surface water irrigation systems are often centralized in an organization because of the highly connected nature of the distribution network. Ground water irrigation systems are typically not as centralized because the delivery system is part of nature, although the connectedness of aquifers and the probable competition between users suggest a need for some centralized control. A valid argument in favor of decentralization is that local decision makers are more aware of their environment than others. Furthermore, taking responsibility for allocating resources motivates the local people to support the needed action. This latter argument, a continuous theme throughout the manual, encourages 1) farmer involvement in the research and development process, and 2) democratic team management.

However, there are situations where central control is more efficient as well as equitable. For example, maintenance and cleaning of a watercourse is a problem in many countries. A major cause of the problem is the general lack of social cohesiveness in the villages to accomplish the work. Water disputes are sometimes a cause of divisions within village societies and at other times water is used negatively against opponents. Since this divisiveness is rooted in the cultural and

historical heritage of villages, it is not likely to be improved by asking farmers at the beginning (head) of a watercourse to contribute their work or money to projects that benefit those at the end (tail) more than themselves. Ideally, local farmers should be able to maintain their own watercourses since they are aware of the conditions. Their maintenance costs should be low and the quality of workmanship good because the farmers are personally affected by the performance of the watercourse. However, local politics may prevent farmers from cooperating. Consequently, it may be worthwhile to use outside control to impose regularly-scheduled cleaning and maintenance of watercourses.* This could be done by requiring farmers to clean the watercourses themselves or by maintaining a crew of workers to go from watercourse to watercourse under the employment of a central agency. Costs could be recovered through water fees paid by farmers. Alternatively, watercourses could be lined, thereby eliminating or reducing the need for cleaning and maintenance.

The issues here involves politics of government agencies. If authority for resource allocation is assigned to those outside the community, the community tends to become dependent upon the agencies making decisions and the agencies tend to preserve their authority. Therefore, it may be a mistake to regard governmental control as a temporary expedient while communities learn how to organize for collective action. Additionally, the creation of a new agency or a new domain for an old one can lead to jealousies between agencies.

Arguments do favor the encouragement of farmers toward solutions at a local level rather than relying upon central authority. Nevertheless, urgent situations or difficult social problems may warrant the intervention of outside assistance.

Preserving Options Versus Gaining Focus

Many uncertainties exist at the beginning of comprehensive water management projects, including those regarding technical feasibility,

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*Limited surveys on some watercourses in Pakistan and Sri Lanka indicated a majority of the farmers contacted were discouraged concerning voluntary cooperative maintenance and would welcome government enforcement of reasonable standards of watercourse maintenance that would be done by farmers.

economic feasibility, and interest groups desiring to affect the direction of solutions. On the other hand, the system is often so complex that information available surpasses the capability of the staff to do accurate analysis. The tendency is for individuals to focus their attention on areas of familiarity which leads to a fragmented, directionless effort. The program manager needs to direct the staff toward a common focus, yet anticipate uncertainties that occur from the research-development process. To attain focus while maintaining flexibility requires anticipation of the alternatives that may emerge from uncertain situations, along with appropriate planning. As events develop, unnecessary alternatives may be abandoned and the staff can direct its attention to remaining solutions.

For example, if a large irrigation system has a serious misallocation between regions due to historical origin of water rights, program personnel should present their data to the appropriate government officials and suggest reallocation. The decision regarding the matter will be made by officials who must consider political realities that may determine the solution. The staff could prepare to respond to a decision to reallocate by determining the optimal means to use added water in the water-scarce region. Conversely, they could also prepare for the alternative by searching for ways to extend the acreage in the water-abundant area and to efficiently use existing supplies in the water-scarce area. With an awareness of program resources, constraints, objectives, and strategic considerations, the project staff can begin searching for solutions.

HOW TO LOOK FOR POTENTIAL SOLUTIONS

Ideas for solutions will generally result from the experience of the project personnel. However, their experiences may be limited to different environments and may not be easily adapted to new situations. There will also be a tendency for staff to defer to those in disciplines most closely identified with the problem. However, since the causes of a problem may involve several areas, the best solution may require a variety of changes. Therefore, the program leaders should actively encourage an interchange of ideas between people of all disciplines and between clients and the staff.

Methods for Generating Ideas

One technique for facilitating ideas among staff members is a formalized brainstorming session on each problem. Before each session, team members must become familiar with program constraints, objectives, and strategic considerations as well as with the parameters of the problems under examination. The manager and staff should independently determine possible solutions. Additionally, the manager should write questions to guide a discussion of the problem. The project manager should encourage comments and solutions before presenting his or her own ideas. This builds self-confidence in the staff, helps gain their input, and generally establishes the manager's credibility. All solutions that can be generated should be recorded without evaluating them. As the discussion slows the manager can offer his solutions if not already proposed. All of the solutions should be evaluated by the group. A quick and easy way to make this evaluation is by vote. Unfortunately, this tends to polarize the staff. A better way is by achieving a consensus when possible.

Obtaining consensus requires development of an objective attitude by the project personnel. This can be fostered by the manager and senior staff if they verbally consider the solutions proposed by themselves and others. The manager should let the discussion continue unless it becomes repetitious. When individuals are convinced their ideas have received fair hearing and their input is being considered in the selection, consensus is usually achievable. Occasionally, the manager may have to make a decision without a unanimous consensus. However, decisions made by consensus produce the most commitment to action. Consequently, time spent in developing a consensus is generally worthwhile.

Important inputs to the session are ideas from farmers and officials close to the problems. Several methods can be used to elicit these views including: key informants, in-depth interviews, and attitude surveys. Ideas should then be presented by team members during the brainstorming session.

Identification of Plausible Solutions

At a later session the staff should identify those solutions that should be further investigated. Those inconsistent with available resources or objectives should be rejected. Aspects of a suggestion identifiable as relevant to the objectives, resources, or strategic considerations should be noted for attention and assigned to individuals or committees for investigation. Personnel must review literature, write to or visit experts, and visit sites where solution ideas may be observed in various stages of development. Constraints that block good solutions should be examined to determine whether they may be at least partially eliminated. For example a government restriction on importing farm machinery might be relaxed in a special case if it can be shown that the net effect on foreign exchange would be positive.

Obviously implausible solutions should be eliminated, but care must be taken not to exclude unconventional ideas simply because they are different. Unconventional ideas may provide new views of problems that are important in considering alternatives. Adherence to checklists of criteria based on program objectives and constraints will help keep unconventional ideas from quick elimination.

Interdisciplinary management gets one of its most challenging tests in this exercise. Individuals from some disciplines are antagonistic toward other disciplines yet are likely to be "conventional" within themselves. Unconventional ideas coming from other disciplines may combine with personality differences to start a hostile exchange. A skilled manager must be able to guide these conflicts toward a constructive conclusion. One method for lowering tension is to hold meetings in a relaxed and pleasant environment such as a "retreat" where other job pressures do not add to the tension of participants. This is not to say that discussion of conflict should be avoided. On the contrary, conflict resolution is a prerequisite to effective teamwork.

Many managers and individuals tend to suppress discussion of conflicts. They prefer to ignore that conflicts exist. If conflicts are not resolved, they often grow to unmanageable proportions. Good conflict resolution, however, can result in group development and good ideas for problem solving. The Project Implementation Manual has suggestions on how to conduct conflict resolution sessions.

CLASSIFYING AND RANKING PLAUSIBLE SOLUTIONS

In large projects the amount of information relevant to each solution may be more than can be used. Furthermore, concentration on the attempt to utilize all the information can distract the staff from their objectives. A method is needed to help assess the quality and quantity of information available to analyze each problem.

One such method is a solutions/criteria matrix as shown in Figure 3. Each column of the matrix corresponds to a potential solution; and each row corresponds to a criterion used to classify the solution. The box at the junction of a row and a column contains summaries of the knowledge about the corresponding solutions with regard to the criterion.

Several versions of the solutions/criteria matrix should be generated. Successive matrices should have fewer solutions and more criteria as the final solutions are chosen and developed, and as more detailed information is gathered for assessment. Figures 3 and 4 illustrate how the solutions/criteria matrix changes between initial classification and final assessment of solutions. The matrix should be kept current so staff are constantly reminded of program direction so they can contribute effectively to its progress.

Groups Affected by Solutions

Groups who might be either positively or negatively affected by the solution through the market, physical environment, political system, or social environment are delineated. Some groups are obvious and include farmers involved in the program, agency officials who will implement solutions, and agricultural laborers who will be affected by new technologies that might replace or require their skills. Less obvious groups are farmer subgroups such as tenant farmers, large farmers, and landlords; non-agricultural rural workers including village craftsmen and merchants; religious leaders; and local officials such as "ditch-riders" or tax collectors. Groups outside of the immediate watercourse area are even less evident, but they may be affected by changes. Especially important is the way in which changed practices in one watercourse may affect the quantity or quality of water available to irrigators in neighboring watercourses or downstream. For example,

Figure 3. First solutions/criteria matrix.

	Potential solutions: candidates for development			
	Solution 1	Solution 2	Solution 3	- - - Solution n
Program Priorities)				
)				
)	(See Tables 1 and 2)			
Program constraints)				
Time requirements				
Interest groups affected				
Uncertainties				
Complementarities				
Resource requirements				

Figure 4. Final solutions/criteria matrix.

	Developed solutions: candidates for implementation		
	Solution 1	Solution 2	Solution 3
Economic productivity effects			
Group 1			
2			
3			
.			
.			
m			
Total			
Income effects			
Group 1			
2			
3			
.			
.			
m			
Resource conservation effects			
Group 1			
2			
3			
.			
.			
m			
Uncertainties			
Group 1			
2			
3			
.			
.			
m			

lining canals or watercourses in some areas might infringe on the water rights of irrigators who pump from underlying aquifers because reduced seepage losses from irrigation channels will likely result in lower groundwater levels and reduced pumping rates. This is thought to be the case in parts of the United States, and specifically Colorado. Similarly, new wells can change the water that is available to older wells (Persian wheels) drawing from the same aquifer.

Effects of the solutions are unlikely to be noticed by groups outside the immediate vicinity until the solution is used extensively during the Project Implementation phase. Then market interactions may be significant when the prices are depressed because of extra crops (presuming that prices are not fixed artificially low already) or when there is competition for scarce commodities such as concrete, fertilizer, or fuel.

Uncertainty of the Solutions

At this point in the Development of Solutions process, uncertainty refers to the technical and economic viability of a solution. For example, a case is considered where tubewells have been designed to "skim" nonsaline water from aquifers in which nonsaline water overlies saline water. The rate and frequency of pumping that can be maintained without drawing saline water has been measured, and a general theory developed to predict what will occur with fresh water recharge, aquifer flow, and a few other conditions. However, a complete description of all the conditions necessary for good predictions is costly. Consequently, only the least expensive data can be collected, and the actual salt content of water pumped by the well might vary as much as $\pm$ 30 percent from that predicted. If the salinity is at the upper limit of this uncertainty, the water may be unacceptable for irrigation. If this should be the case, and such uncertainty is unavoidable, remedies to recoup the farmers' investment must be available. For instance, methods to reduce the salt content of the pumped water, such as through lower pumping rates, blocking off lower parts of the well, or more fresh water recharge around the well during the monsoon season, should be considered. Inexpensive data should be obtained and a generalized theory developed to predict the cost and effectiveness of such remedies.

Another example of the effect of uncertainty would be the lining of watercourses when the pre-development cost/benefit ratio appears marginal and when the effects on the underlying aquifer are unknown. In this case "uncertainty" may refer to prices as well as information about the physical system.

An important aspect of uncertainty that can often be diagnosed before solution development is irreversibility; that is, if a solution can be undone if it proves to be bad. Examples of reversible changes include water scheduling, fertilizer recommendations, and watercourse cleaning. Relatively irreversible changes include the construction of dams or canals, the investment in electricity distribution systems, building of roads, or mechanizing farms. Another type of irreversibility is related to changes in organizational or political structure. Land reform is generally traumatic, and once done it is difficult to change.

A form of uncertainty relevant to irrigated agriculture exists in the requirement for cooperative action. When a solution involves a common property resource such as a watercourse, an aquifer, or in some cases even land, there are likely to be complications of alliances, customs, rules, or laws already governing access to and responsibility for that resource. Moreover, there will be variances in structure and strength even between neighboring watercourses, making generalizations about cooperation difficult. The uncertain flexibility of the interested farmers in adapting to new ways of using that resource is central to the Project Implementation phase.

Generally, solutions are uncertain because of a lack of information about the system. Uncertain solutions require more research before trials are performed on farmers' fields. On the other hand, trials might be justified when the solutions are uncertain and the results are likely to be reversible or remediable.

Disciplines Involved in Developing Solutions

It must be determined which disciplines are more involved in the development of a solution. An example of a solution requiring minimal interdisciplinary work would be fertilizer recommendations that require input mainly from agronomists, especially if the fertilizer supply

infrastructure is already in place. Additionally, uncertainty is relatively insignificant because farmers may try and reject recommendations at a small cost. The same is true for new varieties of seed, recommendations for plant density, and suggestions for amounts of water application. However, solutions that involve changes in multiple parts of the system are both more uncertain and require input from more disciplines.

Solutions requiring new organizations, major capital inputs, or new skills on the part of individual farmers will require at least economic analysis. If the new inputs replace old ones, then it is possible that sociological and legal questions will arise as well. For example, new machinery that replaces labor can put pressure on traditional relations between farmers and laborers, and between landlords and tenants. Many engineering solutions will involve such substitutions.

Solutions involving cooperative action have already been mentioned as requiring thorough understanding of the social system. Water supply and removal solutions nearly always imply some change in use of common property resources.

Entries in the matrix for the involvement of various disciplines should include man months as part of the required base data. In this way research costs of the solutions can be evaluated, compared to their potential returns, and compared with each other.

Time Requirements

Once the solution development is begun, it should be estimated how long it will take before there is sufficient information to determine the acceptability of the solution. If the solution is implemented, it is important to estimate how much time it will require. Time is important, partly because of the uncertainty inherent in developing countries, and because of possible short-term opportunities while waiting for a long-term solution.

Resource Requirements

This item should be divided into requirements for all types of inputs for each group that is involved including farmers, laborers,

artisans, the agribusiness sector, technicians or mechanics, extension workers, government experiment station workers, and other government agencies. Types of inputs include short- and long-term capital investments, credit, technical skills, management skills, water, labor, power, transportation, storage facilities, processing facilities, wholesale and retail marketing facilities, import-export facilities, and foreign exchange. The extent of inputs required at each level can then be compared to the known availability of resources and competing demands in order to judge the practicality of each solution.

Complementarities with Other Solutions

Complementarities may be used in various phases of the project including research. It is possible that the same information is needed for several plausible solutions. For example, rooting depth and evapotranspiration relate to irrigation methods, scheduling, timing of planting, and the value of water supplied to farmers at different points on a watercourse. Another type of complementarity can be used in implementation. For example, consolidation of landholdings into contiguous fields would complement both precision land leveling and watercourse relocation and improvement. Complementarities often occur and should be utilized to reduce duplication of effort and to increase benefits.

Ranking of Plausible Solutions

Culmination of the classification of plausible solutions consists of ranking them and developing a set of major solutions by the staff. Utilization of the solution/criteria matrix facilitates orderly ranking. By involving the whole staff in consideration of each potential solution and by recognizing their common requirements, there should be less tendency for individuals to become identified with certain solutions.

Program objectives should be the primary criteria for ranking solutions. Since the matrix contains information about interests and objectives of groups within the farm system, it is good to compare the program objectives with objectives of the groups affected by the project. It may be possible to redefine program objectives to closely reflect the interests of target groups (low-income farmers, tenants, or

landless laborers) or to mediate between conflicting interests of groups within the farming community. For example, two or more villages may be served by the same watercourse. An objective of the project might be to design a watercourse lining program that will have the maximum net revenue. This may mean that some villages and not others will receive lining. Since a lined watercouse is more suitable for washing clothes and bathing, lining of the section through a village will have high value to the inhabitants. Villagers who do not receive lining will feel denied and may refuse to cooperate in a program that brings more benefit to the other participants. The program objective could be changed to allow a higher cost solution that provides more equitable benefits. In this example, it could be agreed that all sections of watercourses within 100 meters of any village be lined. The program objective could be restated to include the equitable distribution of benefits to all target groups in order to obtain their cooperation in the project.

The actual ranking of plausible solutions should be based primarily on the degree to which they will achieve program objectives. Such ranking requires judgments of the likelihood of success which are somewhat intuitive. It is important, however, to make the judgments explicit. In most cases, the program cannot afford to utilize extensive experimentation to support their judgments, and the staff must reach a consensus on the probable outcomes based on their experience and training. The probabilities of success for different activities within a program are not generally independent because of the complementary issues mentioned previously. Staff must account for interdependencies to make sound decisions regarding the combinations of solutions finally selected.

It is possible to reduce uncertainty by field testing several solutions; all of which have a low probability of success, but for which the probability of at least one success is high. As information on several activities becomes available, alternatives can be narrowed without losing much opportunity for success. For example, delivery losses on watercourses are high. The least expensive alternative would be a program of thorough maintenance, but the success of such a program may be uncertain due to difficulties of insuring the farmers'

cooperation. Another alternative is watercourse lining, but its economic success may be questionable because of the high cost of cement and the poor quality of available lining substitutes. The best strategy might be to begin testing both alternatives (maintenance and lining) with the intent of choosing the best one after more evidence is available on the success of cooperative work arrangements for the maintenance, and the effectiveness of alternative building materials for the lining.

Under some circumstances, it may be that a highly ranked solution might be overlooked for developing several lower ranked ones that require less resources. Alternatively, easy and temporary solutions to a problem may be developed while better but more long-term solutions are researched. For example, introduction of salt tolerant crops could be tried at the same time attempts are made to find ways to lower a high water table through changes in the water supply and removal subsystem.

EXAMPLES

The examples used in this section illustrate how the interdisciplinary group might identify solution ideas, eliminate unfeasible suggestions, and rank the remaining ones for potential development. Literature relevant to on-farm water management spans diverse disciplines and is constantly growing. Therefore, no attempt is made to name definitive sources of information relating to the irrigation problems described in this section.

Example A: The Cotton Emergence Problem

It will be assumed that the overall objective of a project was to increase the productivity of irrigated agriculture with emphasis given to helping farmers with small cultivated acreages. In discussions with government officials, it became clear that falling cotton production was a concern to policy makers because domestic textile mills were having to import cotton. Thus, a goal was to improve cotton production.

During the Problem Identification phase it was determined that both cotton yields and cotton acreages were declining. Farmers indicated insect damage as the main reason that yields were decreasing

and that low yields make cotton production unprofitable. Agronomists noted that cotton yields were far below their potential even without the insect problem, and that most farmers had very poor stands. At first the poor stands were attributed to the seeding rate, but observations of farmers during the planting season showed acceptable rates. Moreover, the seed germination rate was high. This led to the discovery that poor stands resulted mostly from poor emergence due to severe soil crusting problems. Crusting is generally due to the low organic content and high silt content of the soil in combination with the basin method of irrigation and high temperatures.

Conversations with farmers revealed that they knew about the problem and tried to solve it by irrigating before seedbed preparation. This sometimes allowed farmers to postpone the second irrigation until after plant emergence, but this preplanting irrigation requires water during the most water-constrained period. Therefore, the preplanting irrigation is often not done or not properly timed. During a "brainstorming session" team members devised the ideas listed in Figure 5.

During preliminary screening, sprinkler irrigation was eliminated as implausible due to heavy requirements of capital, energy, foreign exchange, and technical skills. Increased wood production was also disregarded because it was outside the ability of the team to change. Conversion of manure to methane and the use of crop residue was left as the plausible means for improving soil structure. All three methods of furrow irrigation were considered plausible solutions although concern was expressed that use of furrow irrigation would favor farmers with large landholdings and violate one proposed priority, that of focusing upon assisting farmers with small cultivated acreages.

The five solutions were then analyzed using a solutions/ criteria matrix (see Table 3). A first priority was increasing cotton production, and the cost of delaying this increase was considered high. The Ministry of Agriculture had already begun a campaign to introduce the use of insecticides for cotton so the staff decided that first ranking should be the development of furrow irrigation. There was a serious question whether to concentrate on hand implements, bullock implements, or tractor implements. Income distribution considerations

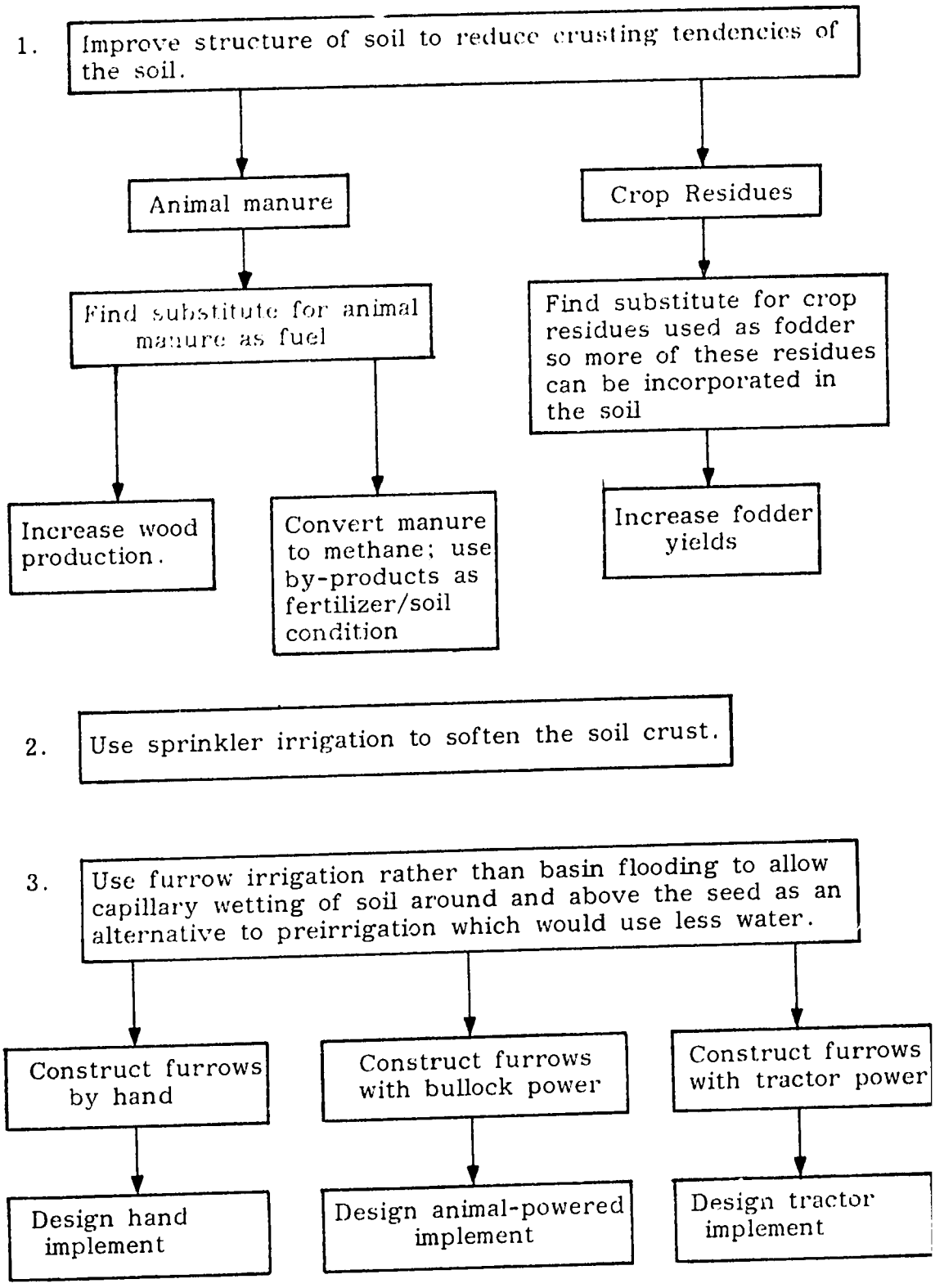

Figure 5. Example of potential solutions for the cotton emergence problem.

Table 3. Solutions-criteria matrix for analysis of research and development strategies for the cotton emergence problem.

PROGRAM PRIORITIES	Increase Fodder Yields	Methane Production	Hand Implement for Furrow Making	Oxen Implement for Furrowing	Tractor Furrowing Implement
1. Increase cotton production					
a. Increase yields					
Improve stands	Via better soil condition (lag of 2 to 5 years)	Soil condition*, N* (Lag of 2-5 years)	+	+	+
Control insects	0		+(by making applic. of insecticides easier)	→	→
b. Lower Costs					
Improve application efficiency of water	0	0	+	+	+
Labor costs	0	0	?(less time per field, but may need more people)	?	+
c. Increase Averages					
Improve profitability	Indirect increase by reducing fodder AGR	0	+	+	+
2. Improve Small Farmer Income	Direct increase	May favor larger farmers	Favors smaller farmers	May favor smaller farmers	Favors larger farmers
PROGRAM CONSTRAINTS					
1. Personnel					
Agronomists (2)	1 man-year	1/4 man-year	1 man-year (Shape of furrows same for all three methods)		
Agr. Engineer (1)	0	1 man-year	1/2 man-year	1 man-year (Same basic design adaptable between oxen & tractor)	½ man-year
Economist (1)	1 man-month	1 mo. (assess feasibility of	2/3 man-year (study differential effects)		
Sociologist (1)	0	2 mo. cooperative use)	1 man-year (study potential acceptance and coop use of tractor power)		
Manager (1)	1/2 man-month	1/4 mo.	1 mo.	1 mo.	1 mo.
2. Budget					
Lab equipment	+	+	0	0	0
Tractor	+	0	0	0	+
Field equipment	+	0	+	+	+
Field assistants	2	1	1	1	1
3. Access to Ministry of Agri.					
Experiment Station	+	0	+	+	+
Agric. University	+	+	0	0	0
4. Three Year Program	Some results in 2 years	Some results in one year/field model in two years	Some results 1 yr/field use 2 yrs	Some results 2 yr/field model 3 yr	
	Impact in 4 to 7 years	Impact in 4-7 years	Impact 2-3 years	Impact 4 years	Impact 4 years
INTEREST GROUPS					
1. Small Farmers	Relatively greatest direct impact	?	HI potential	HI potential	LO potential
2. Labor Farmers	+	++(ability to invest + livestock)	LO potential	MED potential	HI potential
3. Landless Laborers	0	- (current right to use of manure might be lost)	+	+	-(would displace in busy season)
4. Local Mechanics	0	+	0	+	+
5. Cotton Mill Owners	0	0	+ (indirect)	+ (indirect)	+ (indirect)
UNCERTAINTIES	Varietal yield potentials, farmer response, nutrient response, pests, water response, nutritional value	Cost of cookers Danger of explosion Farmer acceptance Labor requirements	Farmer acceptance → Labor requirement for planting Labor requirement for irrigation →		Cost
COMPLEMENTARITIES					
1. Govt. Pest Control Prog.	0	0	+ (ease of application)		
2. Incr. Fodder Yields	0	+	0		
3. Methane Production	0	0	0		
4. Handmade Furrows	0	0	0		
5. Oxen Furrowing Implement	0	0	+(in research-design of furrow) →		
6. Tractor Furrowing Implement	0	0	+(in research-design of furrow) →		
RESOURCE REQUIREMENTS					
1. Farmers					
Management	+	0	+	+	+
Labor	+	+	+	+	-(during planting) ?(during irrigation)
Water	?	0	-	-	-
Cash	+	+	0	+	+
Power	0	0	0	+	+
2. Mechanics					
Management	?	-	0	+	+
Labor	0	+	0	+	+
Cash	0	+	0	+	+
3. Ministry of Agriculture					
Management	+	+	+ (Extension) →		+
Cash	+	+	+ →		+
4. Cotton Mills					
Capacity	0 (+ indirect)	0 (+ indirect)	+	+	+
5. Fertilizer Suppliers	+	-	+ (indirect via increased crop response to nutrients due to stands and water)		

seemed to favor hand implements, but uncertainties about their acceptability, especially for farmers with average- and above average-sized holdings made adoption of oxen- or tractor-pulled implements more likely. In any case, the initial step in developing furrow irrigation was research on the optimal shape of furrows that could be started immediately using currently available hand implements. Since results of this research would be applicable to furrows made by all power sources, an initial decision to emphasize tractor/oxen development did not eliminate a later focus on development of hand implements.

Because this choice freed some of the agronomist's time, it was decided to give second ranking to increasing fodder yields as a long-term investment. It was noted by the agronomists that increased fodder production could improve cotton production in another way. Farmers normally allow weeds to grow tall in their cotton before removal because the weeds are used as fodder. It was hoped that better yields from fodder crops would satisfy the requirements and that demonstration of better cotton yields from early-weeded fields would motivate farmers to weed earlier. Also, increased fodder productivity was attractive because it favored farmers with small acreage and incomes proportionately more dependent on livestock.

Example B: Watercourse Efficiency

Waterlogging and low productivity were the reasons for improving on-farm water management in another area. The Department of Agriculture was convinced that the waterlogging problem was primarily a result of water losses from large distributary canals, while the Irrigation Department thought that farmers' mismanagement of their water was the source of the problem. Information from the Problem Identification phase revealed that farmers near the head of each watercourse over-irrigated and their fields were not level. Since they used basin irrigation, this resulted in low spots that were susceptible to overirrigation with resulting deep percolation. Farmers at the end of each watercourse were more careful with their water, spending effort in leveling their fields during the short time period after harvesting and before the next planting. This led staff to suspect that farmers at the

end got significantly less water per acre than did those near the beginning of the watercourse. Measurements were taken and the delivery efficiency at the end of the watercourses averaged less than 50 percent.

The reason for these losses was suspected to result from a lack of cleaning and maintenance of the watercourses. Discussion among staff raised questions as to whether cleaning the watercourses might increase losses due to the removal of silt which seals the bottoms. The counter argument was that compacting and subsequent siltation would quickly restore the seal and eliminate holes made by roots, insects, and rodents.

When a brainstorming session was held, there were strong opinions as to the best solutions for the water delivery problems. The civil engineer said that lining the watercourse with concrete or masonry was the answer since it eliminates the problem of maintenance. The agricultural engineer pointed out the high cost of cement and bricks as an argument for developing a program of improved maintenance. Others suggested installation of pipe as a possibility. Still others suggested use of chemicals to control weeds, insects, and rodents that were making the watercourse banks more pervious. Another suggestion was to use wells at the midpoints of the watercourses to retrieve the lost water from the aquifer and distribute it to farmers at the lower end of the watercourse where supplies were lowest and application efficiency was the highest. The economist suggested reallocating water to users not on the basis of time but as a percentage of the land served in order to motivate all farmers to take an equal interest in the upkeep of their watercourse.

During the screening session pipe was eliminated as a possible solution due to problems of siltation and capital costs. Pesticides and herbicides were also eliminated because of the potential harm to people and crops. Energy costs involved in pumping caused it to be considered a poor alternative to reducing water losses. Therefore, the three solutions considered the best for development were: 1) watercourse lining, 2) improved watercourse maintenance, and 3) a new method of allocating water. The latter two solutions were not entirely

separate. Another consideration was that a new method of allocating water might make further government intervention unnecessary. The three solutions are displayed in a solutions/criteria matrix shown in Table 4.

Ranking the three alternatives was not unanimous because of the partially subjective nature of the process. At first lining the watercourses appeared best. All the farmers would consider lining to their advantage. Farmers at the start of the watercourse would have a neatly lined ditch to prevent seepage to adjacent fields, those at the end would also have a neatly lined ditch and more water, the Irrigation Department would not have to contend with disputes over poorly maintained earthen watercourses, and the Ministry of Agriculture would not need to assign extension personnel to help farmers improve the watercourses. Delivery efficiency would be greatest under this alternative and waterlogging would be reduced the most. However, the cost of lining would be between $2 and $5 per foot, and if farmers financed this cost, their enthusiasm for lining might diminish. Previous experience has shown that when the government finances the cost farmers do not value the watercourse highly and do not take responsibility for its maintenance. Thus, proponents of lining had to admit that other alternatives had some advantages.

Improved maintenance appeared to be the lowest cost solution. Furthermore, it would lead to fairly immediate tangible outputs since the first watercourse could be completed within a month. On the other hand, farmers might not continue a maintenance program without some incentive or inducement, and the likelihood of farmers organizing was questionable since potential gains to individual farmers varied greatly depending on the location of their farms along the watercourse. The result might be a continuous effort by the Ministry of Agriculture to motivate farmers to maintain their watercourses. However, the Ministry does not like the prospect of having to use its resources in organizing water user groups. Furthermore, there was some uncertainty over the ultimate water delivery efficiency of this alternative.

Lining and improved maintenance competed for the same resources and tended to be mutually exclusive in application. However, improved maintenance and reallocation of water resources were complementary

Table 4. Solution criteria matrix for analysis of research and development strategies for the watercourse efficiency problem.

	Lining of Water-courses	Improved Maintenance of watercourses	Reallocation of Water
PROGRAM PRIORITIES			
1. Reduce Waterlogging	Most efficient delivery system; highest capital cost	Efficiency not known; low cost	Efficiency not known; least cost to govt. maximum farmer responsibility
2. Increase Productivity	+	+	+
PROGRAM CONSTRAINTS			
1. Personnel			
Agri. Engineer	2 yrs	3 yrs	3 yrs
Hydrologist	2 yrs	2 yrs	2 yrs
Civil Engineer	3 yrs	2 yrs	2 yrs
Agronomist			
Sociologist	1 yr ( )	2 yrs (org. of farmers into coop assoc.)	3 yrs (study effects on social cohesiveness and feasibility)
Economist	9 mos (B/C)	9 mos (B/C analysis)	1 yr (design compensation mechanism)
2. Budget			
3. Access to Ministry of Agriculture			
Policy	0	must agree to user assoc.	0
Operations	0	must agree to user assoc.	0
4. Access to Irrigation Dept.			
Policy	0	0	must agree to change
Operations	0	0	must police change
5. Three year deadline	1 yr research 2 yrs development 10-15 yrs implemt. and impact	1 yr research 1 yr development 10-15 yrs implemt. and impact	2 yr research development 1½ yr implementation impact 5 to 10 yrs.
INTEREST GROUPS			
Farmers: Head	small positive	Variable	probably negative
Tail	large positive	positive	positive
Local Irrig. Dept.	+	0	-
National Irrig. Dept.	+	ambivalent	-
Ministry of Agric.	+	-	+
RESOURCE REQUIREMENTS			
Farmers			
Labor	0	off season; shadow price $\lambda 0$	off season
Water	+	+	+
Cash	-	≈0	
Ministry of Agric. Extension workers	+	+	+
Dept. of Irrigation Management	+	+	0
UNCERTAINTIES	- Cost of lining - Life of lining	- Efficiency of delivery - Ability of farmers to cooperate with unequal incentives	- Feasibility - Costs in social conflict in watercourses - Method of measurement - Method of control
COMPLEMENTARITIES			
1. Lining	0	0	+
2. Maintenance	0	+	0
3. Reallocation			

because the same watercourse design could be implemented regardless of the water allocation scheme adopted. Moreover, much of the information needed to assess the potential for water users' associations is also needed for assessing the feasibility of a compensation scheme for water reallocation. The trade seemed to be between high delivery efficiency, high cost, and loss of local initiative; and lower delivery efficiency, lower cost, and more local autonomy. Improved maintenance was ranked first because of its low cost, potential for fostering cooperation among farmers, and its potential complementarity with any future water reallocation scheme.

Lining of watercourses was ranked second because of its highly tangible results. Reallocation of water was ranked last, mostly because of the uncertainty with which it was associated. Nevertheless, the staff economist was assigned to research the alternative for six months and then conduct studies with the sociologist to determine farmer reactions to the idea In this way, the option would be investigated further to determine its feasibility as a long-term solution.

CHAPTER III

DETAILED DEVELOPMENT OF SOLUTIONS

Groundwork for solution development should have begun in problem identification and during the identification and ranking of solutions. In this chapter it is assumed the earlier phases have provided a basic understanding of the system, rapport with farmers, a clearly defined set of priorities, and a detailed plan of action. Responsibility for execution of the plan is with the entire group. The manager has special responsibilities for coordinaing activities; motivating the staff; and providing the conditions, personal example, and leadership that will help the group work together and involve their clients in the research and development tasks. This chapter outlines principles for the testing and adaption of solutions (Figure 6), and uses the two examples introduced in Chapter II for illustration.

METHODS OF DEVELOPING SOLUTIONS

Devising Goals

By this time the team should have narrowly defined objectives, and when research begins these should be refined into operational objectives and corresponding criteria for measuring the achievement of objectives. In addition to the detailed research and development activities that have been planned (Chapter II), tasks must be assigned, expected results defined, and deadlines set for completing the activities.

Some guidelines for setting goals may be useful. Goals should be set participatively by the staff. Goals imposed by the manager do not produce commitment for accomplishmen by the project staff. Each goal should have criteria for monitoring progress toward its completion. Generally, self-monitoring is best since it fosters commitment and does not detract from control when measurements are available for the criteria.

The goals and criteria must be written precisely. First, the goals must be stated as desired results. Steps to reach the results are then defined. For example, if an engineer's goal is to find low cost methods for watercourse lining, the engineer must be able to describe the goal

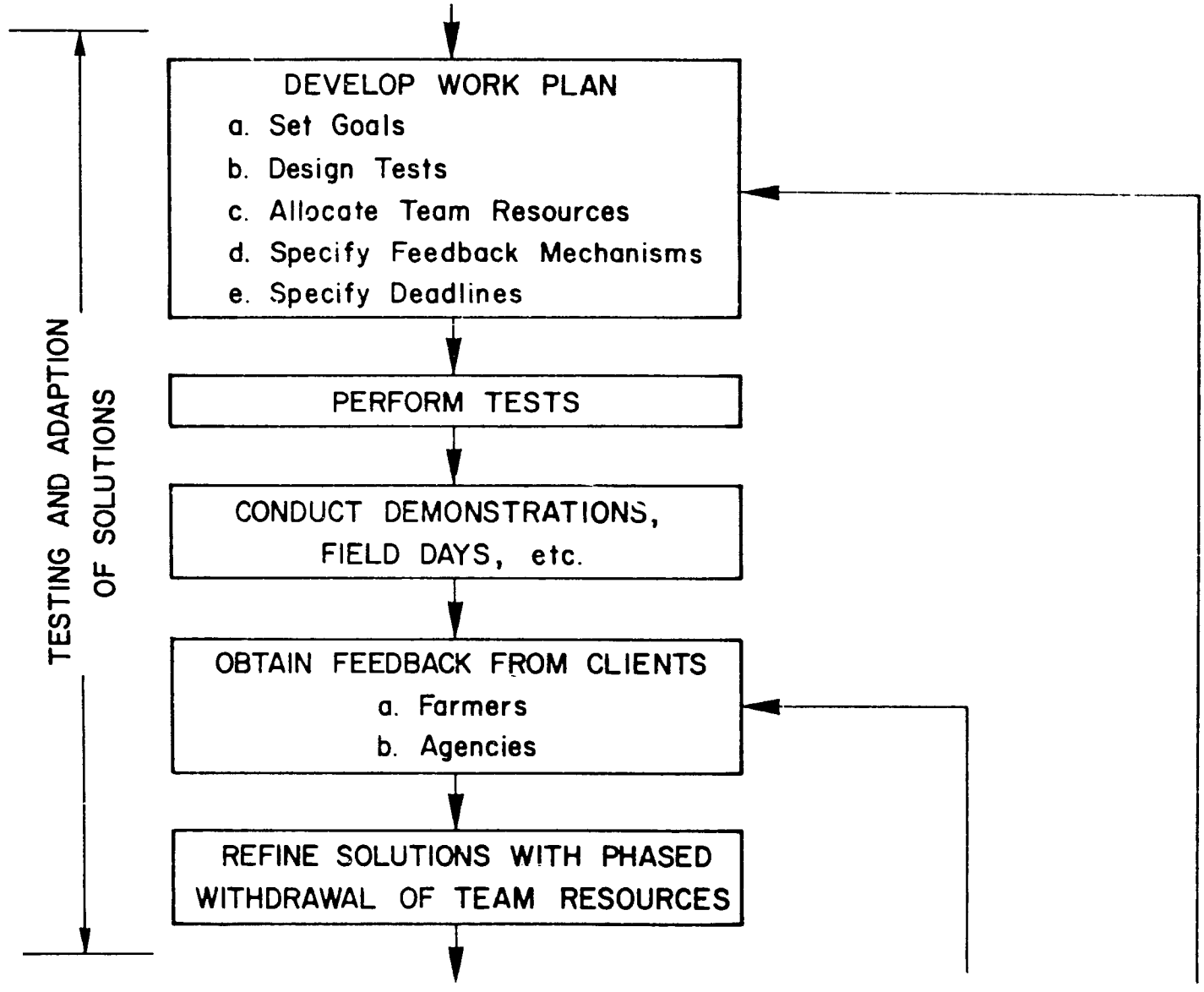

Figure 6. Flow diagram for the Testing and Adaption of Solutions subphase of the Development of Solutions phase.

and the approach to its achievement. Completion dates for each step should be stated. The first step might involve testing alternative materials for water retention, durability, and labor costs. The types of materials and specific tests should be described. Criteria might include a description of a satisfactory low cost watercourse.

Communication and Feedback

The issue of communication is fundamental to the project's success. There are principles that can be followed to facilitate effective communication. These affect both the accuracy of information transmitted and the morale of the personnel. Techniques for improving feedback is detailed in the Project Implementation manual.

Critical feedback is of particular concern to a team manager because if it is done well it can be the primary means by which the staff can correct mistakes. It is best if feedback is given continuously, naturally, and informally during the course of a project rather than waiting for major evaluations. Major evaluations are essential, but feedback should be continuous.

Farmer Involvement

A special type of communication is that between the staff and its farmer-clients. Project personnel must remember that farmers who adopt a new technology or practice must fit it into their existing cropping system and their social and physical environment as well. While the agronomist or engineer may be more familiar with the intricacies of the innovation, the farmer is more familiar with the context into which the innovation must fit. Therefore, time spent keeping farmers familiar with the basic motivations and principles behind proposed solutions result in farmer feedback that will help identify other alternatives as well as erroneous assumptions or faulty logic of the team. Some situations virtually demand farmer participation such as the design of implements for bullocks. The designer knows the purpose of the implement but the farmer is more knowledgeable about the abilities and limitations of the bullocks. In other situations the need for farmer input is less obvious and researchers must use it to ensure no surprises are likely to occur.

There is a tendency that must be controlled if technicians are to establish rapport with farmers. Because of their broader experience and training in problem solving, the technician who listens closely to the farmer will often perceive the new solution before the farmer. At this point there is a temptation for technicians to claim the solution their own and thereby emphasize the importance of their contributions to the development process. This often forces the farmer into defending the existing situation to maintain self-esteem. Additionally, farmers have been known to sabotage demonstrations comparing new and current management practices. When such polarization develops farmers may refuse to acknowledge and adopt the new practices.

This sequence of negative reactions can be avoided if technicians will help farmers understand the background of a problem, enlist their help in thinking of new solutions, and openly acknowledge and publicize the farmers' role in developing the answer(s). By following this course, the technicians allow the farmers to feel a personal involvement in choosing the best alternative, and they become objective experimenters rather than defensive proponents of the currently used techniques.

A dividend of farmer involvement is that the farmers become excellent promoters of the best new solutions. They also become extremely effective in describing the advantages to appropriate government officials and other farmers considering implementation of the new solution.

Research Strategies Requiring Collective Action

The common property characteristic of irrigation systems frequently requires collective action to implement a solution. However, development of such solutions usually does not lend itself to controlled and replicated experimental approaches; rather, the alternatives must be developed through a "learning while doing" process. This is termed the "case study" approach.

Similarly, through a "learning while doing" process, the staff builds a basis for prescribing education and incentives that motivate farmers to take the action that will improve their production system. Unfortunately, the nature of communities prevents translation of this

action into sets of rules or guidelines to be handed over for implementation. Therefore, it is suggested that when solutions require collective action by farmers, the Development of Solutions phase should overlap the Project Implementation phase so that personnel involved with the initial stages of implementation can gain experience by being part of the research and development group. If this is not possible, then the training program for implementation staff must include field experiences that require collective action by farmers.

In controlled experiments it is expected that some trials will fail. In the case study approach it is important the solution not fail both for the good of the farmers and for the credibility of project personnel. Consequently, it is important to choose the most cooperative farmers to compose the initial group. After the solution has been successfully demonstrated, it can be tried on more difficult groups or under less favorable conditions.

If the staff cannot convince a significant majority of the farmers that they may expect a personal gain from the solution, there will be no cooperation. Furthermore, even a small, strategically placed minority who feel they are not benefiting can subvert a project. It is essential to find ways in which some needs of all farmers can be served by the proposed solution. This strategy requires an investment of time to understand farmers' needs and to develop components in the program to compensate those who perceive they will receive less than their share of the primary benefits.

As an example, the Colorado State University experience in Pakistan included a major effort to develop a program of collective watercourse improvement. In the initial case study it was apparent that many farmers near the beginning of the watercourse were negative toward collective efforts at watercourse improvement. When the situation was considered only in terms of delivery efficiency, their position was understandable. Delivery losses are directly related to the distance of a farmer's field from the beginning of the watercourse. Thus, many farmers with land at the start of the watercourse felt they had enough water and could not see how improvement in the delivery efficiency of the watercourse would be personally beneficial. Close observation of water management, the condition of the watercourse, and

discussions between farmers and researchers led to the conclusion that watercourse improvement held many benefits for farmers near the beginning or head. For example, the head reach of the watercourse carried water almost every day of the week. This also meant that the head reach leaked almost continuously and portions of adjacent fields were waterlogged and useless for cropping. Constructing better banks reduced water losses in half, restoring the waterlogged land to production.

Farmers near the head often had fields that were slightly above the level of the watercourse due to sediment deposits from the canal water. Each time the farmers wished to get water onto these fields, they had to build a high earthen dam to raise the water level, and then patrol and repair the watercouse which was full. Much water was lost and this was a difficult, time-consuming and frustrating task. Improved banks made the process more efficient and concrete diversion structures, a standard feature of the program, facilitated the task of backing water onto high fields. In some watercourses a simple jet pump designed for this purpose was installed to use energy of water falling from tubewell outlets to lift canal waters to levels from which they could serve high fields near the pump.

Because upper reaches ran most of the time, they posed significant barriers to traffic involved in cultivation and harvest of fields in these areas. Inclusion of a few culverts in the upper reaches provided the needed access and incentive for many of these farmers to participate enthusiastically in the program. The lesson of this experience is although collective projects are difficult because they are complex, their complexity allows flexibility in design so they can benefit all potential cooperators.

Benchmark Studies

Generally, research done for on-farm water management projects is not like a laboratory experiment where only one variable is allowed to change over a large number of observations. Rather, the team is trying to introduce several changes into a complex system and to adapt them until they achieve the desired results. When it is impossible to control other inputs that could affect the outcome, they should be monitored and estimates should be made of their effects.

Monitoring can help to spot unforeseen changes. These may be caused by interactions between components or by unforeseen inputs. Changes are often apparent only when a current measurable condition can be related to the quantified condition prior to the field trial. Thus, it is essential that benchmark studies that define the situation prior to imposing any changes on the farm system precede field trials in order to fix a reference point.

Much benchmark information may be available from the Problem Identification phase. If not, the solutions/criteria matrix can be used as a guide to the measurements and observations needed and what subsystems will be directly or indirectly involved. Other questions that may be answered include expected changes in each of these subsystems, and the measurements or observations that can be made to assess these changes.

Sometimes benchmark studies are quite simple. For example, the effect of cleaning a watercourse can be determined by comparing the measurement of delivery efficiency before and after cleaning. However, most benchmark studies become more complex. For instance, if the objective is to determine how much water can be saved annually by a regular cleaning program, the delivery efficiency should be measured several times a year to establish an estimate of the average delivery efficiency. This average delivery efficiency will be compared to the average delivery efficiency under a more frequent and regular cleaning program. Benchmark studies can be very extensive and time-consuming when effects of water management on overall crop production or socio-economic factors are evaluated since the affected population is large and numerous measurements are needed to obtain accurate averages.

Phased Withdrawal of Support

Perhaps one of the most significant extraneous inputs is the project staff themselves. They have expertise unlikely to be possessed by members of established agencies to implement solutions; they have access to authorities in agencies that can ensure cooperation of local officials; they are not allied to local families, communities, or organizations; and they generally take a positive attitude toward change.

Towards the end of the work, it must be determined how the staff will withdraw from the project. One way is to gradually withdraw their support to a level commensurate with what is likely to be delivered by the implementing agency. If project personnel have designed a system utilizing a bund and water control for flood irrigated rice, these techniques need to be applied by an extension agent with comparable background and training that will be available to those participating in the Project Implementation phase. By shifting to a monitoring role, staff can find ways in which to modify the equipment, technology, solutions, training or motivation of the agent, and other related tasks until the extension agent can successfully bring about change. For example, simpler instruments for determining elevation differences may ensure that extension agents will have access to the instruments. Better, more expensive instruments may demand special skill or care.

To get the solution demonstrated initially on a farmer's field, there is a strong temptation to "buy the participation of farmers" through government provision of inputs. If this is done it is necessary to reduce government inputs in subsequent field trials to test whether the program will be accepted by the farmers when they assume costs that the government cannot afford in a large program. This test should be done as soon as possible in the Development of Solutions phase so the program can be adapted in the series of case history field tests. The huge cost in time, money, and human resources in mobilizing a project, plus public announcements about production goals for the project, develop momentum in the implementation phase that makes changes difficult, embarrassing, and in some cases impossible to accomplish. As a precaution, a new case study designed to test a lower level of external support should be located sufficiently far from the earlier study areas to avoid comparison by farmers.

Representativeness of Field Studies

The uncontrolled nature of field trials has already been mentioned. A closely related problem is the degree of generality of field trial results. Results of physical experiments can be replicated within a single field trial so that statistically reliable results are obtained for

that time and place. However, generalization to entire countries, continents, and other time periods should be resisted until evidence is obtained to support the generality of conclusions.

The role of social sciences deserves particular emphasis in this regard. A field trial dealing with a single watercourse is a statistical sample size of only one for observations of the communities. Therefore, it is important for social scientists to determine whether other communities within related regions are similar or dissimilar, and to assist in planning case histories to determine the applicability or changes needed in the solution.

Attention to External Effects

Because of the complexity of irrigated systems and the limited understanding, it is likely that application of solutions from one area to another will have unanticipated effects. Consequently, care must be taken to look for external or indirect effects that escaped attention during the ranking exercise. It is impossible to comprehensively list potential external effects, otherwise it would have been done in the solution/criteria matrix, but there are some ways to look for such effects. One of the most obvious is the marketing system about which several questions can be asked. Does the new demand for particular goods harmfully compete with other uses? Are there facilities for handling added outputs? Is crop storage a problem? Is it possible that powerful interests control major inputs or that these interests are the sole buyers of output? Is is possible that certain laborers will be harmed by new management practices or use of new machinery? If a new crop is adopted, what happens to those involved in the processing of the old one?

Another source of external effects is the water resources. Because it is a common property resource, irrigation water is often the center of an institutional system of customs, laws, and alliances that govern its use. If widespread use of a solution such as tubewells causes a change in access to the water resource there may be pressure on the institutional system. If the system had been designed to anticipate changes, such as the assignment of water rights to the

aquifer, it may help adaption. If not, the staff should anticipate the potential conflict and suggest methods for ensuring equitable and efficient outcomes.

Pressures toward structural change in the social system are more difficult to a project than are physical or market changes. This is particularly true in traditional societies where social obligations are intertwined with economic functions. In some systems labor is supplied to a chief or village headman in return for claims upon his influence in disputes. Variants of such reciprocal obligations are found in extended family systems and landlord/tenant relationships. Moreover, social status may define access to land ownership, education, and professions. If a change in an irrigation system affects the value of and demand for labor, lower classes may gain or lose leverage against these socially defined barriers. There is no accurate way to predict or assess a change in leverage and other resulting social aspects until after it has occurred. Thus, social scientists must carefully monitor the progress of field tests to detect signs that indicate a change in leverage.

More predictable is resistance by privileged classes to changes that redistribute wealth. In fact, resistance from landlords or wealthy farmers may be a sign the proposed solution will have unanticipated redistribution effects.

Deciding When to Concentrate Efforts

Chapter II prescribed a strategic response to certainty by developing alternative solutions with implementation contingent upon outcomes of research or events outside the control of the program. Utilizing a contingency plan for action will work for awhile. However, eventually decisions need to be made to emphasize development of one set of solutions or another. This is difficult for facilitating teamwork because as work progresses individuals tend to become identified with particular solutions. Additionally, they will support solutions they have helped develop. Two methods can be used to eliminate this tendency including: 1) involvement of individuals in more than one solution and recognization of all their contributions so they are less likely to identify with only one approach; and 2) an early agreement of specific times to reassess progress on each solution. It should be clear these techniques

are meant for eliminating many of the solutions that have been studied. Such decisions should be made by using criteria agreed upon in advance. To use the cotton emergence example, if an agronomist is spending a large amount of time on fodder improvement, which has clear long-term payoffs, but his services are needed to conduct tests to determine optimal furrow shape, which has a more immediate payoff, the group may decide to stop or delay work on fodder improvement.

If possible, this decision should be made at a time previously set. In this way the decision is anticipated and is not as likely to be regarded personally. If the agronomist had been periodically involved in the furrowing work all along, the shift to that part of the project might be easily accomplished.

EXAMPLES

To convey an idea of how the principles in the preceding section are applied, the two examples introduced in Chapter II are utilized in this chapter. It may be helpful to refer back to those examples and in particular, back to Tables 3 and 4.

Example A: Cotton Emergence Problem

After the decision was made to rank development of the oxen/tractor furrowing implement first and increasing fodder yields second, the manager instructed the staff to specify goals under each alternative, identify general tasks toward these goals, and allocate responsibility for each task to project members. Assigned members then specified how they would perform the duties, noting input needed from other team members and farmers. Staff members were also encouraged to think of ways to involve farmers in some of the other activities. Goals specified by the project members, their assigned responsibility, and the duration of each activity are shown in Table 5. Examples of the steps specified by different individuals as requested by the manager are listed in Table 6.

Example B: Watercourse Improvement Plan

After deciding to give first priority to cleaning and maintenance of watercourses, the staff decided to slightly reinterpret their decision.

Table 5. Example of goals, responsibility and scheduling of each activity for the cotton emergence problem.

	Year 1											Year 2
	M	A	M	J	J	A	S	O	N	D	J	F
Find cooperating manufacturers (AE)												
Negotiate contract specifying cost sharing and rights to sell implements												
Purchase needed manufacturing equipment (AE)												
Purchase tractor able to furrow and plant (AE,A)												
Implements for use in determining irrigation labor requirements												
Survey potential cooperating farmers												
a) Farm budgets (E)												
b) Farmer social position (S)												
Determine soil properties on sample farms												
Water retention (A)												
Capillary action in soil (A)												
Compaction (A)												
Resistance to implements (A)												
Percolation (A)												
Field topography (A)												
Determine ability of oxen												
a) Power (AE)												
b) Speed (AE)												
c) Precision (AE)												
d) Availability (E)												
Build Prototypes (AE)												
a) Ridger only												
b) Ridger/seeder												
c) Ridger/seeder/compactor												
Determine optimal ridge design (A,AE)												
a) Wetting of seed												
b) Water use												
c) Labor use												
Use imported equipment on farmers' fields												
a) Labor requirements for irrigation (E,A)												
b) Water consumption (A)												
c) Effectiveness of insecticide applied (A)												
d) Effectiveness of fertilizer (A)												
Take designs to farmers' fields												
a) Bullock (AE)												
b) Tractor (AE)												
Improve fodder production (A)												
Test fertilizer response												
Test alternative fodder crops												
Test alternative harvesting techniques												
Get Ministry of Agriculture involved												

Table 6. Example of work plan by discipline for the cotton emergence problem.

Duration		Activity
		Agricultural Engineer
2 weeks	1.	Find cooperating manufacturers. Contact local mechanics and craftsmen who make implements for tractors or bullocks. At the same time contact dealers and importers of tractors to assess ability to manufacture prototypes and expand production during implementation.
2 weeks	2.	Negotiate contracts with one or more manufacturers to build, according to design, various configurations of ridging implements. Preference will be given to local manufacturers over importers even if some training and equipment are necessary. One-year contracts will be given to at least two manufacturers subject to renewal upon conditions of performance.
1 month	3.	Purchase imported tractor and implements so that agronomists can begin experiments to determine labor, water, and other requirements for furrow irrigation on farmers' fields.
	4.	With aid of an anthropologist, secure cooperation of farmers with oxen to test oxen capacity for work. Tests to include power, speed, and stamina will be conducted using sleds with various amounts of weight over periods from one hour to three days and at various rates. There should be teams of oxen with differing ages to ensure reliability of results. Follow-up tests will be scheduled in the heat of the planting season to judge effects of heat on bullock efficiency. Report by July 1. (Economist will submit a report on the availability of oxen at different times during planting season.) Cooperating farmers will be shown sample fields with ridges and the objective of the ridger/planter will be explained. In return for the farmers' services during planting season, the team's tractor will be used to cultivate their fields.

Table 6. Example of work plan by discipline for the cotton emergence problem (continued).

Duration		Activity
		Agricultural Engineer
	5.	Use preliminary results from March/April tests to construct prototype ridgers. These will initially include: 1) a ditching plow only, 2) a ridger with a planter incorporated, 3) a ridger with a planter and a compactor. Objectives will be to keep weight low and construction simple. Seed depth and spacing should be variable. Field testing of prototypes will first be at experiment station and then on farmers' fields. Some field trials of ditchers will be done by May. Chief concerns will be shape of ridges and capacity of bullocks. Other prototypes ready for first tests by fall planting season. It is necessary that there be continuous feedback from cooperating farmers and close cooperation with the agronomist.
		Agronomist
2 weeks	1.	Purchase tractor and implements for experiments in cooperation with agricultural engineer.
2 weeks	2.	Contact potential participating farmers in cooperation with the sociologist/anthropologist and agricultural engineer. Discuss program objectives. Determine their interest and if they are eager to participate, make plans for plot layout, soil sampling, and other tasks.
1 year	3.	Begin tests of soil properties to continue through a calendar year; finish in April of Year 2; initial report June 1 this year. Results will be input to optimal ridge shape design.
Duration of project	4.	Begin optimal ridge design study. Must consider trade between optimal environment for plants and demands put on implements. In particular, will determine payoff for compacting versus planting under loose soil. Results of compacting on emergence and vigor will be

Table 6. Example of work plan by discipline for the cotton emergence problem (continued).

Duration		Activity
		Agronomist
		available by July 1. Results of ridge shape, seed placement, and depth of furrows on water use and yields will be available by December 1. Experiments will be done on farmers' fields and carefully explained to them. Emphasis will be on explaining the experiments as research for practices to increase yield, with significant possibilities of success and failure. Optimal ridge configuration will require continuous and close coordination with the agricultural engineer.
1 year	5.	Use imported tractor and implements to determine labor and water use in irrigation. A number of farmers will be used and each will have both a furrow irrigated field and a control field. Economist will cooperate in assessing demands on labor and water budgets for both furrow and control fields. Effectiveness of insecticides and response to fertilizer will be tested. Again, careful explanations of every step and measurement will be given to farmers. After the initial irrigation using furrows, farmers will be asked for their suggestions regarding matters such as shape, spacing, and compaction of ridges. This will be repeated at regular intervals throughout harvest. Where feasible farmers' suggestions will be tried so they understand their role as experimentors and decision-makers.
1 year or more	6.	Improve fodder production. Farmers will be surveyed to determine all sources of fodder; what farmers consider important qualities of fodder; animal requirements of fodder (farmers' estimates); and the different varieties of each crop distinguished by the farmer.

Table 6. Example of work plan by discipline for the cotton emergence problem (continued).

Duration	Activity
	Agronomist
	Tests will begin to determine fodder response to fertilizer. Non-legumes: NPK-, NP-, N- Legumes: PK-, P- Alfalfa and other foreign crops will be tried. Two-year legume fodders will be tried (not now done). Alternative harvesting techniques will be used. Initial results on fertilizer and new varieties should be available by December 1. A decision will be made by January 1 whether to: a) Discontinue research, b) Get Ministry of Agriculture or a donor agency to take over, or c) Continue research.

Experience indicated that sections of watercourses near villages were the least efficient resulting from human and animal use of the watercourse. Since that use would continue, it was decided to consider lining those sections as a compromise. Moreover, the economist had determined that such lining would enhance use of the watercourse for washing and bathing and this would be considered a benefit. Others argued that it was impossible to quantify the benefit. However, the counter argument was that if villagers were willing to pay for the lining, they were strongly supporting its development. Thus, an agreement was made to continue some work on reducing the cost of lining in conjunction with development of a cleaning and maintenance program. Table 7 shows the goals specified by project members, and the responsibilities and duration of each activity.

The task assignments for two individuals is given in Table 8. The economist and civil engineer were used as examples because the solution requires collective action and involves the water delivery system.

Summary

Examples just given show plans for approximately the first year of two multi-year solution developments. Eliciting and integrating inputs from farmers and all disciplines represented by the staff was the means suggested for developing good solutions. It is worthwhile to note that explicit provision was made for decision making. In the cotton emergence problem the agronomist was to present evidence after one year for a decision on fodder improvement. In the watercourse improvement problem all plans delineated October as the time to decide which watercourse would be improved first.

Special emphasis should be given to the field day described on Table 7, but not mentioned in the individual plans of action. It is hoped to attain two audiences: farmers outside the watercourse and officials of relevant agencies. Rapid adoption of collective innovations such as watercourse improvement requires enthusiasm. This can be generated positively through field days. First, if host farmers feel responsible for their innovation, attention will generate pride and enthusiasm. This enthusiasm will spread as visitors react positively to the host farmers' enthusiasm, and the host farmers will become even

Table 7. Example of goals, responsibility and scheduling of each activity for the watercourse improvement plan.

TASKS	Year 1											Year 2
	M	A	M	J	J	A	S	O	N	D	J	F
Conduct detailed survey to more accurately determine causes and location of losses in watercourses (AE/H)												
a) Head, middle, and tail segments												
b) Outlets												
c) Near villages												
d) Water source												
Study of optimal configuration of earthen watercourses (CE/H)												
a) Shape												
b) Compacting												
Development of improved outlet (CE)												
Develop lower cost lining (CE)												
a) Earth and cement												
b) Fiberglass plaster												
Find potential cooperating watercourses (S)												
a) Find cooperative villages												
b) Do benchmark surveys S,E												
i) Water budgets A												
ii) Delivery losses												
iii) Cropping patterns/yields												
iv) Labor availability and use												
v) Social profile												
vi) Application efficiencies												
Determine history of cooperation in watercourse maintenance (S,E)												
a) Laws and enforcement												
b) Performance												
c) Differences between watercourses												
Analysis of social and economic factors related to quality of maintenance (S/E)												
a) Water supply												
b) Productivity of land												
c) Tenure system												
d) Social structure												
e) Social cohesiveness												
f) Relationship with government agencies												
*Determine strategy for improvement of first watercourse (Team) and choose watercourse (TEAM)												
Organize Watercourse (S,AE)												
a) Meet with leaders to explain												
b) Decide assignments and schedules												
c) Train work crews (S,AE,CE)												
Perform Improvement												
a) Initiate work (S,AE)												
b) Ask for feedback (S,AE)												
c) Make adjustments and complete (AE)												
Evaluate results with farmers												
a) Measure delivery efficiencies (A,EH)												
b) Demonstrate to farmers (AE)												
c) Meet with farmers to discuss results (S,AE)												
Hold field day (TEAM)												
a) Other farmers												
b) Dignitaries												
Assess first watercourse improvement (TEAM)												
a) Design considerations												
b) Cost considerations												
c) Farmer cooperation												
d) Changes in farm practices												
e) Changes in farm income												
Begin plans for next trial (TEAM)												

Table 8. Example of work plan by discipline for the watercourse improvement plan.

Duration		Activity
		Economist and Sociologist/Anthropologist
4 months	1.	In cooperation with the agronomist conduct benchmark surveys of watercourses. Obtain data on cropping patterns for the past years, labor budgets, water budgets, oxen, tractors, dairy animals, land tenure, and application efficiencies for irrigation. Use data to construct crop budgets to incorporate into a linear program. Generate shadow prices for water at different points on the watercourse for different sized farms and different seasons. Determine present means for facilitating maintenance of watercourses.
6 months	2.	Determine the history of cooperation in watercourse maintenance. In particular, what laws and regulations govern maintenance, in fact and principle? What has been the enforcement mechanism and how has it worked historically? Are there regional differences? What legal and administrative arrangements have been used to good effect in other countries? The legal questions are most efficiently answered by a legal expert, therefore arrange to hire a consultant within three months for a period of two months. Meanwhile, search the literature and survey regional irrigation departments to assess their perceived roles and their perception of farmer performance. Farmers in the region of the study will be consulted to determine their understanding of the laws.
1 year	3.	Determine what factors seem to explain the quality of maintenance of watercourses. Factors to consider include: water supply, shadow price of water, potential productivity of soil, social structure, social cohesiveness, and relationship of leaders with irrigation department officials. From this conclude which cooperating farmer groups are most and least likely to continue a watercourse maintenance program once it is initiated.

Table 8. Example of work plan by discipline for the watercourse improvement plan (continued).

Duration		Activity
		Economist and Sociologist/Anthropologist
October, 1st year	4.	Decide which watercourse to improve first. Use information about likely cooperativeness, existing delivery efficiencies of watercourses, and potential net benefits from improvement. Economist and sociologist/anthropologist play major roles here due to the need to 1) assure success on the first attempt and 2) assess projected net benefits.
	5.	Assess watercourse improvement. Repeat benchmark study after improvement and compare realized net value versus before net value versus projected net value. Find discrepancies between "after" and "projected" values and look for causes of differences. Assess distribution of benefits and participate in feedback and joint work on an incentive system to encourage maintenance.
		Civil Engineer
18 months	1.	With hydrologist, test for optimal watercourse configuration by slope, soil type, capacity, and amount of use. Determine the savings due to compacting for each configuration after 1 week, 1 month, 3 months, 6 months, and 1 year. Consider labor requirements, management requirements and ease of maintenance as well as delivery efficiency. Discuss the objectives with farmers, encourage them to express opinions and encourage their suggestions. Where possible, incorporate their thinking in design of the trial.
6 months	2.	Develop an improved outlet which has negligible leakage when closed. Try metal, concrete and rubber, and plastic sheets.
1 year	3.	Develop a lining of minimum cost for sections near villages. Try: 1) plaster over earthen/cement bricks, 2) fiberglass plaster over cinder blocks. Consult with farmers on design of areas near villages for buffalo baths.

Table 8. Example of work plan by discipline for the watercourse improvement plan (continued).

Duration	Activity	
	Civil Engineer	
December 1st year	4.	Supervise watercourse improvement and monitor performance of leaders in making decisions where possible.

more enthusiastic. Of course, agency officials are likely to be more skeptical, but they too are affected by the enthusiasm of others. Because the government agencies will need to cooperate in at least implementation, and may be responsible for it, feedback from agencies when solutions are still formative will enhance ability to develop a solution acceptable to those agencies.

CHAPTER IV

ASSESSMENT OF SOLUTIONS

Solution assessment has been performed all through the detailed development of solutions described in the previous chapter. A separate assessment phase (Figure 7) is distinguished to emphasize the importance of explicit and detailed comparisons between alternatives.

Assessment begins with a formal assessment of information related to each solution set. This information is summarized in a revised version of the solutions/criteria matrix used to display solutions and their characteristics. Before detailed solution development there are many solutions with limited information. As solution development proceeds the number of solutions decreases while the information about the remaining solutions increases in quantity and quality until, at the solution assessment stage, the alternatives are few, and their characteristics are numerous.

Given sufficient information to make meaningful comparisons of alternatives, assessment proceeds from a review of the purpose to an analysis of the requirements and effects of each solution set. Requirements of implementation are included by answering the following questions:

1. What actions are required or expected to occur and how are these to be enforced or motivated?

2. What are the resource requirements from each group in the system?

3. What kind of schedule can be used for implementation?

4. What is required of involved agencies and are they able to perform their tasks?

Results of implementation include effects on the economy, environment, social structures, and politics of involved individuals and communities. Evaluation of these effects and the costs are the basis for assessing solutions and choosing the best alternatives.

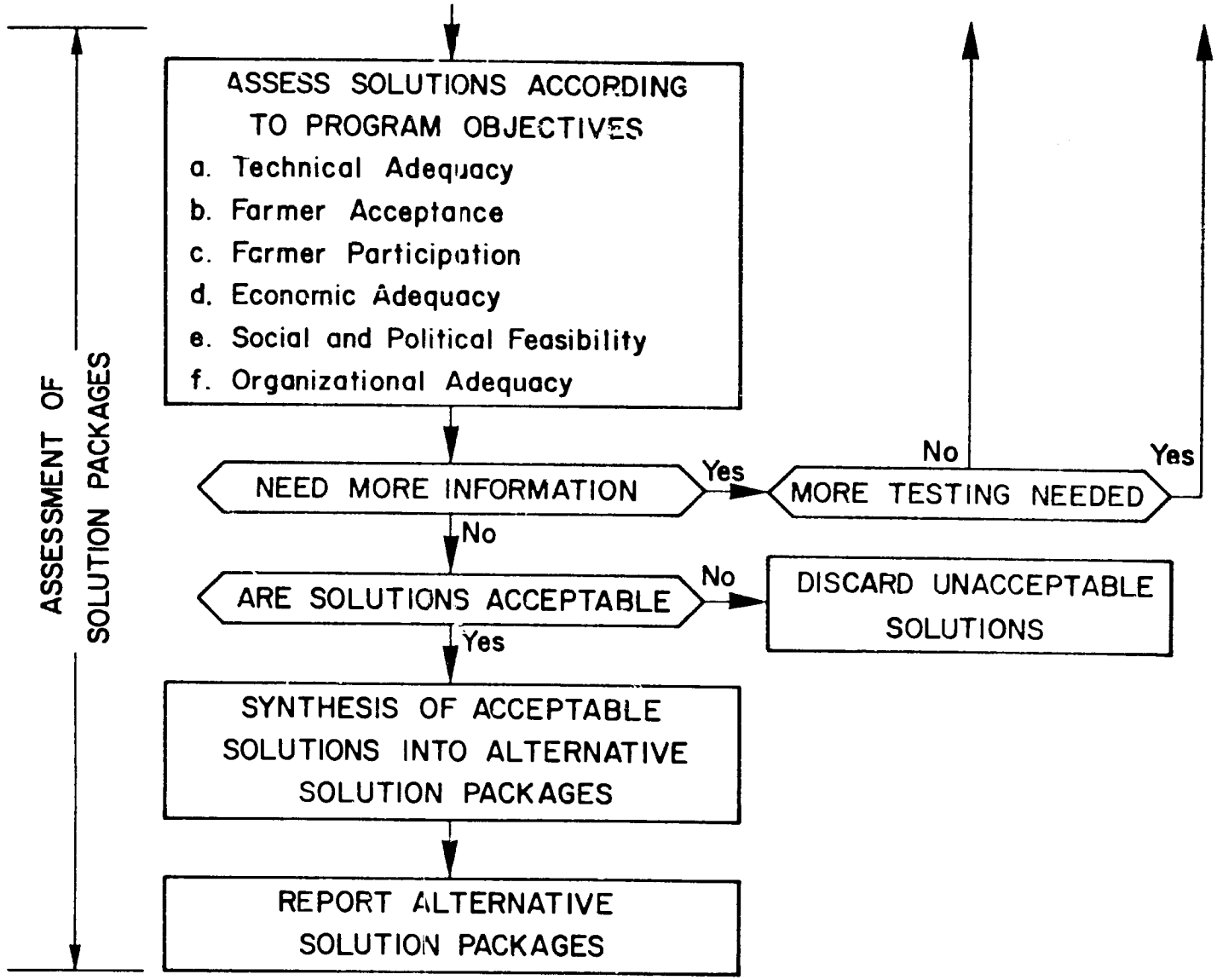

Figure 7. Flow diagram for the Assessment of Solution Packages subphase of the Development of Solutions phase.

REVIEW OF OBJECTIVES

There are two reasons for reviewing program objectives at this point: 1) assessment and comparison of the solutions can be done more purposefully and efficiently if objectives are in mind, and 2) any additional information obtained may indicate that operational objectives should be revised. A need to change objectives could arise because operational objectives were based on faulty understanding of the system or because there are one or more inherent contradictions within the objectives of the government. If the latter occurs, a formal case should be made detailing evidence of the contradiction(s) and requesting a prioritization of objectives. For example, perhaps the government has specified objectives to increase grain production and help farmers on small acreages. Field studies showed that land fragmentation has led to a proliferation of watercourses which decreased water supplies to individual fields and reduced cropped acreage. One suggestion to increase productivity was land consolidation. However, an unanticipated result of consolidation was eviction of tenants by landlords who found their newly consolidated holdings easier to manage. This effect was increased productivity but tenant farmers cultivating small acreages were adversely affected by this solution.

If land consolidation was a government objective, then evidence of conflict between lower priority (land consolidation) and higher priority (help for smaller farmers) objectives should be presented. If only two high priority objectives were given such as to increase productivity and help small farmers, there may still be reason to submit evidence to guiding agencies. In particular, if productivity gains from land consolidation or other solutions are high enough, the government may consider the loss of equity a cost worth paying for the gain in productivity. In this case, the trade-off is between two high priority objectives.

Feedback from farmers may also motivate a change in objectives. For example, increased grain production is the high priority objective of the program. Discussions with farmers reveal if they have increased water supplies they will grow oranges instead of food grains because of low prices on food grains and higher returns on oranges. This

evidence indicates that either the market priorities are different than government priorities or that government interference with prices (such as subsidies) is causing a distortion in the market.

A common cause of market distortion is a government objective to keep basic food grain prices low to reduce probabilities of under-nourishment of the poor. The need to increase food grain production is probably tied to a need to decrease expenditures of foreign exhange for imported wheat. Project personnel may be able to show the costs of maintaining artificially low domestic prices on food grains while paying world prices to import grain. It may be that higher grain prices would be cheaper than production subsidies and importing grain.

In this case, as in many others, resolution of previously unrecognized conflicts between government objectives may provide a major part of the solution to the problem. In either case, evidence can be organized to substantiate the farmers' case and to motivate appropriate changes in government policies.

Whether or not there are conflicts between objectives, the operational objectives of the project should be reviewed with the guiding agencies. An opportunity should be made to revise the objectives in view of additional information or recently developed needs. Having reviewed and perhaps refined the direction of the program, staff can begin a systematic assessment of information collected during field trials.

IDENTIFICATION OF NEEDS FOR FURTHER TRIALS

It should be determined with what degree of certainty each solution set can be rated according to relevant criteria. The first step in answering this question is to examine each element in the solutions/criteria matrix and assign probabilities to the entries. In some cases, entries will be outcomes of replicated controlled experiments, and are subject to confidence intervals computed by statistical analysis. In most cases, entries will not be based on replicated controlled experiments, but on results of field trials in a few areas plus sample surveys used to establish the representativeness cf field trial sites. Consequently, most probabilities must be arrived at through subjective judgment and group consensus. It is particularly important to identify

any uncertainty and then decide what the costs may be of reducing it through further study. The cost of added study must be weighed against the possible costs of not obtaining the information. Costs should not be regarded as consequences. For example, if a decision is made to implement a solution that fails due to insufficient knowledge of the hydrologic structure in regions outside the vicinity of the field trials, one cost is the capital invested that cannot be salvaged. Another decision, harder to define monetarily, is the time lost in pursuing an incorrect idea. Loss of credibility of the government agencies is another cost that is difficult to quantify but may be important.

Certain criteria can be used to assess the vulnerability of a solution package to uncertainty. One criterion is divisibility. It can be determined if it is possible to begin implementation in small increments and to adjust along the way. Examples of divisible solutions are field level technologies such as furrowing implements, new seed varieties, and pesticides. A somewhat less divisible solution is the lining of watercourses. A substantial investment is involved, but it can be done in stages; first lining the upper reaches and proceeding toward the end as the lined upper reaches demonstrate their value and their problems are solved. Solution packages that are divisible provide the opportunity to "learn while doing." Other solutions such as large dams are not divisible, and potential consequences of uncertainty can be disastrous. In this case, substantial investment is justified to avoid uncertainty.

Closely related to divisibility is reversibility. A solution is reversible if it is possible to return to the old method with little or no cost. The same examples that were given for divisibility apply to reversibility. New seed varieties can be abandoned in favor of the old, fertilizer use can be abandoned or cut back as costs rise, and the cost of abandoning a new seed planter is the initial cost of the planter. Conversely, the cost of abandoning a hydroelectric dam is prohibitive and the government cannot practically reverse its decision.

This manual has repeatedly stressed flexibility is a quality that may redeem an indivisible or irreversible decision by providing several options for going forward. For example, building of a dam was

proposed with the intent of using all of the water to irrigate a particular valley. However, the water table rose quickly and salinized a large portion of the land so only a portion of the stored water could be used in the valley. If surface drainage could be achieved at reasonable cost or there were areas outside the valley that could use the water, the project could still be successful.

Consequences of uncertainty may be marginal for the program as a whole but devastating for a few farmers. If this is the case, the staff should assess the potential for shared risk-bearing in which farmers would be insured against unreasonable loss.

If the staff decides that more information is needed on some solutions, it is still possible to concurrently proceed with assessment of other solutions. Furthermore, it may be possible to assess the uncertain solutions and limit the possible negative consequences by determining which situations involve the "worst possible" consequences. In the meantime, further tests should be performed to narrow uncertainties to acceptable levels.

TECHNICAL ADEQUACY

Technical feasibility should have been demonstrated by this time. Assessment of technical adequacy must examine the broader question of reliability of the solution under changing conditions. Input-output relationships should have been specified by defining permissible ranges for input and output quantities and qualities. However, other questions must be asked. What if the quality of inputs is outside the permissible range? Will all the necessary inputs be available? If not, are there substitutes? For example, tubewells run by diesel engines require fuel, oil, spare parts, and mechanics. Can local mechanics be trained to maintain and repair the motors, and is it possible to manufacture spare parts locally? If fuel becomes scarce, is it possible to switch to electric motors or steam engines fired by crop residues?

For example, it was assumed that a watercourse lining design performed reliably in field trials. The project group should try to anticipate problems that could frequently occur and consider the effects on the objectives. It should be determined to what degree the quality of materials can be reduced without appreciable loss of structural

quality. Other questions include: to what extent can variation in soil conditions endanger the structure? If a structure is endangered due to poor materials, workmanship, or soil conditions, what can be done to rectify the problem and at what cost?

Essential to reliability is quality of operation and maintenance of irrigation facilities. What are the minimum standards of operation and maintenance that would result in acceptable performance? For example, public tubewell engines are expected to function for a given time at rated capacity without overhaul assuming prescribed lubrication and cleaning. If lubrication and servicing is done only half as often as prescribed what is the expected life of the well before overhaul? What is the cost of overhaul?

Do demands for operation and maintenance fall within the capability of local people? If not, what training is needed? Once trained, how likely are operators and maintenance people to stay? Is there a means of contracting with private individuals or companies for operation and maintenance? Would some sort of leasing arrangement increase quality of operation and maintenance?

Reliability also applies to seed and chemical inputs. If a crop is prone to attack by certain insects, and is therefore dependent on use of pesticides, how sensitive are results to precisely timed and placed applications? If farmers are to make the applications, what are reasonable standards to expect? If chemicals to be used by farmers are toxic for humans, what precautions can be taken to reduce hazards? Supposing that precautions are not followed, what are the hazards? Are there reasonably effective antidotes?

Storage is also subject to reliability analysis. Both seed and fertilizer require special storage and handling. What are reasonable standards to expect from storehouse managers? What happens when performance falls below the standards?

FARMER ACCEPTANCE

Lack of farmer acceptance is evidence that the farmer has been excluded from the development process. If the farmers are involved and share responsibility for design and testing, researchers will have continual feedback concerning barriers, and acceptable solutions will

have evolved. Conversely, enthusiastic acceptance by farmers should be carefully analyzed. It should be determined whether this enthusiasm is derived from real benefits or intensive encouragement by professionals, and whether the test area is representative of the region selected for implementation. In either case, each solution should be assessed against a set of criteria relevant to the types of farmers in the implementation region.

Profitability

The profitability to the farmer of each solution can be tested by means of farm budget analysis performed for representative farms considering a range of prices, yields, and resource availability that could occur in the region.

Compatibility with Farm Management Practices

Several questions can help assess the solutions compatibility with existing farm management practices. Do changes fit with other methods of husbandry, both for crops and animals? For example, do new irrigation methods require new seeding and harvesting methods? Does a new crop decrease the amount of fodder available for animals? Can a new implement be adapted to animal power?

Complexity and Compatibility with Farmer Skills

Another important issue is whether farmers can effectively utilize the innovation. Can farmers operate and maintain the new technology? Do they depend on a sole source for service and parts? To what degree are they vulnerable to market conditions, for instance, prices of petroleum, parts, and fertilizer.

Compatibility with Social and Cultural Environment

This includes the farmers' obligations to their household or to their kinship groups. Does a change require the farmers to alter their reciprocal work arrangement with relatives or their participation in community work groups? Is the solution compatible with traditional modes of cooperation between farmers? Does it alter the work demands on women in farm households? For example, a new, labor-intensive

technology may seem to fit a period of low farm activity. But are there nonfarm social activities normally scheduled in that period? If so, it may be that farmers do not perceive the time as "leisure" and that either their social relationships must suffer or the new technology will lose some of its effectiveness.

FARMER PARTICIPATION

Emphasis has repeatedly stressed farmer participation in the Development of Solutions phase. The objective of a water management improvement program is not just to initiate a physical change at a designated time but to facilitate and establish improved management practices. The farmer is the ultimate agent for change and must be convinced that the new method has more benefits than the old or the management practices will not be changed. A few governmental agents have sufficient credibility that some farmers will take their advice and adopt a new practice. A larger percentage of the farmers may accept the new solution if its benefits are clearly demonstrated to them. However, many farmers will not adopt these methods. Most farmers who participate in the processes leading to selection of a solution, and invest their resources, will understand the solution well enough and be sufficiently supportive to continue the new management practice.

An example of the wrong approach in soliciting farmer participation occurred in the Mohlenwhal Khurd area near Lahore. The farmer was told that his current water and fertilizer practices were not the best and that project staff would show him how to obtain improved yields. His cooperation was "bought" by the staff who agreed to pay for the seed and fertilizer and said he could take all of the wheat. He was asked to divide his field and was told to continue his own management practices on one half, while the project staff used improved management practices on the other. He began to perceive the demonstration as competition against the project members. Instead of appreciating the doubled yield due to the improved practices, he felt that he had failed and that his failure would cause him to lose respect in his village. He refused to endorse the new practices or even to admit to his neighbors that the new practices had increased yields.

Willingness of farmers to participate in new solutions involving their time and resources in the planning and implementing stages is one of the best methods to achieve a successful solution. By this investment of their time and resources they are endorsing the solution in the most significant way.

It should be determined if the solution changes the amount of the farmer's control. For example, private tubewells give farmers a new degree of resource control. However, a cooperative scheme for land leveling and cultivation may diminish individual farmer control over those functions even though they improve the precision of water control. To assess whether the proposed solution increases or decreases the farmer's autonomy, major decisions the farmer makes during a cropping year should be listed before and after implementation of the solution. If dependence on others increased, it should be noted who gained control along with the farmer's method for communicating grievances to that authority. Loss of autonomy is not always bad and farmers recognize the need for reduced autonomy where there is an important common property resource.

Some cooperative programs such as watercourse improvement require unanimous participation by all the farmers concerned to be most successful. As discussed previously, a general prerequisite for unanimous participation is that benefits be designed for all concerned in the program. For example, farmers at the beginning of watercourses do not benefit significantly from decreasing water losses from the lower reaches. Additional benefits such as culverts to improve access to their fields and structures to facilitate their control of the water are often essential to gain their participation. In other cases, there will be benefits not anticipated or comprehended by the farmers such as elimination of seepage damage to their land. In these cases, education such as a visit to another improved watercourse to see these benefits may achieve the desired participation.

ASSESSING ECONOMIC ADEQUACY

A distinction is sometimes made between financial assessment and economic assessment of a proposed project. Both are concerned with income and costs, and both use the same methodology in computing rates of return. However, "financial assessment" is used to define

analysis of the changes in incomes and costs from the perspective of individual entities in the economy such as farmers, laborers, cooperatives, banks, irrigation departments, marketing firms or boards, national government, lending institutions, and donor agencies.

"Economic analysis" defines the analysis of the aggregate of these benefits and costs adjusted to consider the results not reflected in market prices or administered prices. The distinction is useful because it emphasizes to those who equate economic analysis with financial analysis that the economists generally have a broader perspective than market profitability. The distinction also serves to remind the economist of the importance of using financial analysis to consider individual incentives and income distribution. In this manual, financial assessment is regarded as a part of economic assessment, although there are times when financial analysis needs to be separated to allow for financial planning of the Project Implementation phase.

Levels of Economic Analysis

Three levels of economic analysis consist of individual, regional, and national. The first includes farmers, laborers, private businesspersons, and government agencies, and is a financial analysis. The second, regional economic analysis, considers what might be considered externalities* as well as any secondary effects such as employment of unused resources. The third, national economic analysis, accounts for aggregate supply and demand relationships, effects of the solution package on foreign exchange and compensates for distortions in prices from "true" social values.

Individual Financial Incentives

Farmers are commonly the group singled out for economic analysis, but are not the only group that should be considered. Others include laborers, tenants, landlords, private businessmen, local functionaries,

*Externalities are effects of the project on those not directly involved. These can include physical effects such as changes in water table depth due to increased pumping or increased efficiency of water use. Externalities are sometimes considered to include market effects such as a rise in the wages of agricultural labor due to increased work opportunities provided by the project.

and government agencies. By nature, irrigation systems involve common property resources. Thus, whole watercourses or water users' associations may, for this purpose, be designated as financial "individuals."

Farm budgets, which are prepared in the Problem Identification phase, represent "before solution" cases. During and following field trials, other budgets were prepared to document economic effects of the solution as it was adopted. Comparison of "before" and "after" budgets show the financial costs, benefits, and net effect of the solution for individual farmers. If decisions to adopt solutions are only at the farm level (for example, use of improved land leveling techniques or use of furrow as compared to basin irrigation); then little needs to be done in assessing financial impacts on other entities except to ensure that increased commercial crop production can be handled by marketing outlets.

Externalities

It is possible that individual decisions will affect others who have no control in decision-making. For example, increased use of tubewells may lower the water table and increase pumping costs for others or it may cause intrusion of saline water into overlying sweet water used by others for irrigation or domestic purposes. If this is the case, equity requires some method of compensation or collective control which may involve legal and political questions to be discussed below.

Collective Decisions

If decisions to adopt a solution are made collectively, the issue of incentives is more complex. Individual budgets must be considered, but social and political factors also enter the decision more strongly than in an individual decision. Solutions that benefit some more than others leave those with smaller benefits feeling slighted, leading to situations where cooperation disintegrates. For example, watercourse lining tends to benefit those towards the end of the watercourse more than those near the beginning. Since those near the head are often relatively affluent, they may choose to forego benefits of lining in order to block benefits to those further down the watercourse. However, because the costs of lining are collective and the benefits individual,

there may be ways to allocate costs in proportion to benefits (presuming individual costs are always below corresponding benefits), or it may be possible to accommodate and benefit those at the beginning through added costs such as purchasing and installing additional culverts in order to achieve net benefits for all.

Trade-offs such as these should have been identified in field trials so that the sharing of benefits and costs of collective projects meet with as little opposition as possible. Related factors were discussed in the "Farmer Participation" section.

Financial Analysis and Risk

Costs and benefits can be compared only when they are expressed in terms of value at a common time of reference, for example, the value at present. Computation of the present value of an investment requires that a detailed schedule of benefits and costs be devised. Up to now, financial and economic analysis are the same. However, now financial analysis becomes concerned with the practical matters of flow of funds. For example, if a large initial outlay is required and if benefits begin to accrue only after one year, there is a problem of paying now for future income. Interest rates, sources of credit, and detailed assurances of income to meet credit terms are concerns of financial analysis.

Delayed returns also increase investors' risk since future income is less certain than current costs. If individual farmers are the investors, they may hesitate to adopt the change because of their averseness to risk. There is extensive literature in economics on risk averseness of farmers, but from an implementation viewpoint, the precise nature of the farmer's risk averseness is not so important as the order of magnitude. A commonly used "rule-of-thumb" is that an investment must have a benefit/cost ratio of at least 2:1 before small farmers are likely to consider its use. Consequently, economic analysis of risk should allow for individual risk averseness, and emphasis should be on finding methods to decrease individual risk.

Several factors affect the magnitude of risk relative to the farmer's income, and consequently, the degree of the farmer's reluctance to invest. Several of these reasons are discussed elsewhere in this manual but the discussion here pertains to individuals. One is the size of the

largest possible loss relative to the farmer's wealth. Closely related to this is the divisibility of the investment. If an investment is highly divisible, such as use of a new variety of seed, the farmers can choose their own level of investment. An example of the opposite extreme would be a land consolidation program that can threaten the farmers due to uncertainty of the quality of the land they will acquire in return for land they know well.

Another property of change affecting risk is reversibility. The two examples given with respect to divisibility are also relevant to reversibility. If a new seed variety is unsuccessful, it is possible to return to the old variety in the next year, but if a farmer loses as a result of land consolidation, he is unlikely to find satisfaction without considerable difficulty if at all.

One element of risk especially relevant to irrigation is control. If a farmer is asked to trade absolute control over a modest amount of water for joint control with other farmers over a larger portion of water, the farmer may be reluctant. Thus, changes in structure or location of outlets, conversion from private tubewells to a public irrigation system, or transfer of water scheduling authority to higher and less accessible officials all present potential for loss of control that farmers may not be willing to risk.

Credit and Risk Sharing

Credit for farmers with small landholdings is a problem in many developing countries. High administrative costs, diversion of funds from development to consumption, and low rates of repayment are nearly universal. Irrigation systems provide potentially easy control of credit application and repayment for investors. Experience has shown that administrative costs and default are lowest when repayment is made through farmer associations. This would be especially true of publicly-owned irrigation systems where water use could be contingent upon group repayment of debts. This is appropriate for investment in watercourse improvement, but could also be used for improvements on individual farms, such as precision land leveling, terracing, placement of bunds, or installation of sprinkler systems. Provision could also be made for farm operating loans for seed, fertilizer, pesticide, or tractor services.

When credit is given in this way, much risk can be transferred to the government agency which has the choice of canceling or deferring loan payments in years of poor harvest, or of including an insurance premium in loan payments. If the government is also the purchaser of crops, loan repayment becomes especially simple.

Future Prices

Projection of future prices interjects an element of uncertainty into the economic and financial analysis. A standard method of coping with this uncertainty is to do sensitivity analysis with farmer budgets. Output prices, input prices, and resource availability can be varied to show when the solution becomes unprofitable. Solutions are insensitive to price changes if the output prices are far below projected levels or if input prices must rise significantly above projected levels to make the solution unprofitable. If not, judgments must be made about the probabilities of unprofitable futures. Sensitivity analysis is a standard procedure in linear programming treatments of budget analysis, and is explained in many linear programming textbooks.

Regional Economic Assessment

Secondary effects of projects are often analyzed on a regional basis or in the geographical area within which most of these effects are expected to occur. Secondary effects are those changes in income in sectors other than those directly affected by the project. For example, increase in income for ginning mills due to increased output by cotton farmers, who have received additional water, is considered a secondary effect as are increased incomes to retailers who sell more consumer goods to the farmers. Some economists argue that these effects should not be counted when the resources diverted to the region would have been used elsewhere. Furthermore, the most common method for assessing secondary effects is input/output analysis which is not suited to accurate representation of rapidly changing economies.

There is, however, a case in which secondary effects are unquestionably valid for inclusion in costs and benefits. When there is unused capacity that the project would bring into production as secondary inputs, their opportunity cost is zero and their contribution to production as reflected in wages or in their "marginal value product"

is a benefit to the region. The most important example of unused capacity is unemployed labor. Since most agricultural economies have seasonal unemployment, a project that uses off-season labor creates secondary benefits equal to the wages paid.

An important aspect of secondary effects is changes in income distribution. Improved labor intensive water management practices can increase the demand for and value of farm laborers, leading to increased incomes for landless laborers. However, use of sophisticated new technologies can eliminate use of landless laborers for two reasons. Special skills or knowledge may be required to operate the new technology, and the machine may actually replace labor as in the case of harvestors, threshers, cultivators, or center pivot sprinkler systems. There is a direct effect on laborers employed and a secondary effect on other laborers whose wages are changed due to changes in demand. Therefore, while secondary effects should not generally be counted as benefits or costs in an overall benefit cost analysis, they can be analyzed for income redistribution.

National Economic Assessment

Staff members tend to consider the project on a local scale. Nevertheless, government objectives will usually be expressed in economic terms at a national level (for example to increase incomes of subsistence farmers, reduce rural to urban migration, and achieve national independence in grain production). Therefore, the project economist should be familiar with national priorities and be able to act as an intermediary for the team and government economic planners.

Shadow Prices

Many developing countries suffer chronic shortages of foreign exchange and periodic acute shortages of basic goods and services such as cement, fertilizer, and port facilities. The same economies generally suffer shortages of skilled and semi-skilled laborers. Almost as frequently, prices of these goods and services are regulated and do not reflect their social value. In such cases, national cost/ benefit analysis

must differ from individual financial analysis in that actual prices are replaced by shadow prices.*

The difference between market and "shadow," "social," or "planning" prices presents a problem to project planners. The project will never have enough information to compute true shadow prices on its own, yet it may be impossible to get a set of definitive shadow prices from a government planning agency. The best a project may hope for is a set of prices for a few important factors such as labor and foreign exchange. If these are available, the project can feel relatively comfortable about their cost-benefit analyses.** If they are not available, it is incumbent upon the project economist and the team leader to contact appropriate agencies to learn as much as possible about plausible ranges for shadow prices on these factors. Such price ranges can then be reflected in a set of alternative cost-benefit analyses showing how various alternatives fare under different assumed shadow prices.

Price Elasticity for Agricultural Output

A factor often overlooked in cost benefit analysis of agricultural projects is the possible fall in prices due to project induced increases in production. If production is mostly in domestically consumed commodities, and if the project region is large, the increased output may conceivably reduce farm income (price elasticity of demand for food tends to be low). If the increase in production is mostly exported, if the region is small, or if the increased output will substitute for imported commodities there may be little change in price level. An

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*A "shadow price" is the best estimate of the real value of a product or resource whose market value is distorted by factors such as subsidies and price controls. For instance, market prices of irrigation water to farmers are often far below its real or shadow prices because the govenment has subsidized the construction and operation of the storage and delivery systems. The shadow value is the estimate of read value to the country.

**There are two extensive treatments of project appraisal appropriate to developing countries in the development literature:

1. Little and Mirrlees (1974)
2, Dasgupta, Sen and Margolis (1972)

Both are theoretical, and a more practical guide, based on the Dasgupta et al. volume, is Hansen (1978).

important consideration for irrigation projects is inter-regional effects. A project which increases water available to one region and not to another producing similar crops has potential for causing serious negative effects on farm income in non-project regions.

Government pricing policy can have important effects on the price elasticity of demand for agricultural products. It is common for governments to maintain artificially low prices on staple foods to subsidize urban consumption. This has the effect of increasing imports and depressing domestic production of food crops in which prices are controlled. In such cases, it may be difficult to achieve greater production of staples without adding incentives for the farmers. Raising prices of staples is often politically dangerous, but subsidizing inputs such as fertilizer and water is not. However, such subsidies may not have the desired effect because subsidized inputs tend to be used on more profitable crops, thus requiring costly, and only partially effective policing of the use of subsidized inputs. Whatever the case, budgeting data provides a good basis for evaluating the potential effects of prices on crop production.

Pricing Water

The value of water in a given region at a particular time of year can be computed from budgeting analysis or from the functional relationship between production and water availability to the crop. It is unlikely that these prices will be used to allocate costs of water to users because water prices are often fixed by custom or charged indirectly through land taxes. Nevertheless, budget-derived shadow prices are useful to planners when they are faced with allocation of water between regions. Water prices are essential for identifying "economically optimal" solutions for a water management improvement program. Guidelines for computing water prices are discussed in the appendix. The method suggested uses farm budgeting and linear programming. This method applies to both computations relevant to individual farmer decisions and to evaluation of projects using "social" prices on inputs and outputs.

Long-Term Land Tenure Effects

A classical dilemma in agricultural development arises from the tendency for average farm size to increase as better managers buy lands of poorer managers, using mechanization to spread their managerial abilities over larger land areas. While this generally improves management and production, it tends to force more of the population into the landless labor category which is often subjected to serious hardship. Government concern over this tendency results in restrictions on size of landholdings in some countries, while in other countries there are efforts to restrict mechanization.

As long as there is a land market, this tendency will continue. This is particularly true when new, more productive technologies are being introduced because better managers adopt the new technologies more quickly and use them to better advantage. Moreover, land acquisition is more attractive as farming becomes more profitable. This transition may first manifest when tenants become landless laborers. Later the problem becomes more obvious when landless laborers are displaced by machinery.

In general, displacement of labor by machinery does not save the cost of wages to society but only to the farmer. Responsibility for the support of displaced labor falls on society in general, while savings in wages displaced by machines accrue to individual farmers. The scope of this dilemma is much broader than any individual project, and ideally, the answer is contained in government policies.

SOCIAL, POLITICAL, AND LEGAL ADEQUACY

Collective action and management is a common element in irrigation systems. If the system is controlled by the government to the farm gate then the politics of management are distinctly different than if control stops further upstream in the water delivery network.

Farmer access to decision makers in a government agency are either indirect, through local members of the legislative body, or nonexistent. In this case, political adequacy is unlikely to become an issue except in cases where two or more agencies share jurisdiction over the system. Assessing the political factors impinging on water management in cases of shared jurisdiction is difficult because of

natural tendencies toward interagency jealousies. Nevertheless, such assessment is necessary because good solutions that must cross jurisdictions may be considered useless unless cooperation can be achieved between the agencies. A general rule is to avoid solutions that cross jurisdictions, and failing that, assure and convince the agencies that each agency has something to gain through cooperation. Interaction between the agencies during field trials of the solutions may not reveal the whole story because the improvement program will have high level sanction and be closely scrutinized by project members and authorities above the agency level. Local agency representatives will, therefore, feel compelled to cooperate. In contrast, Project Implementation occurs at lower levels in many locations remote from higher authorities. Consequently, the same pressures for cooperation will not be present. Thus, cooperation during implementation will be highly individual and specific to local political conditions.

If agency control stops short of the farm boundaries, farmers must act cooperatively to manage part of water delivery and removal. In this case, questions of social cohesiveness become critical. Assessment of the effect of the solution package on social cohesiveness may not be representative of the range of possibilities if it is based only on one or two field trials. Thus, project sociologists/anthropologists must be prepared to assimilate knowledge of the surrounding area that is combined with experience gained from field trials.

Part of the socio-political assessment needed to refine the project can be obtained through incorporating the answers to the following questions in the solutions/criteria matrix for various groups affected. If there has been disagreement between groups concerning the solution, did this disagreement occur along the same divisions as existing disagreements or rivalries? Did the disagreement lead to a standoff or were farmers able to compromise? If there was no compromise, is it possible for government agency action to affect a compromise? Did the team's action contribute to disagreement? If so, was the cause a result of the presentation, taking sides, or in the failure to recognize interested parties? Can the team error be rectified in the implementation stage or is there a need for new field trials?

Generalization of Local Experience

Local political conditions may not include social conflicts existing in other regions. Conflicts may have been resolved due to strong social cohesiveness in the field trial area. For example, if landlord/tenant relationships are very good in this area, investment in water delivery and application hardware may occur smoothly as landlords and tenants agree on their respective shares of investment costs. However, in other areas where relationships between tenants and landlords are strained, the introduction of new hardware might be impossible or lead to eviction of tenants.

There may be potential for creating support for changes among seemingly uninvolved groups. For example, improved drainage and watercourse maintenance could decrease waterlogging in neighboring areas. Once this is demonstrated, support for such a program could come from farmers outside the watercourse area. This raises the question of how best to inform such potential beneficiaries and enlist their support. A strategy that uses the demonstration effect to mobilize widespread support should become a part of the implementation plan.

ORGANIZATIONAL ADEQUACY

Three aspects of organizational adequacy should be examined including 1) existence of physical facilities and manpower to support implementation, 2) organizational structure to mobilize support, and 3) an incentive system to guarantee organizational responsiveness to farmer needs.

Physical Facilities and Manpower

In this assessment the team should recognize that procuring essential facilities and manpower may be more or less difficult in the implementation phase than it was in the field trial phase Items likely to be in shorter supply as the program is expanded to implementation are those for which other uses compete and are in relatively fixed supply such as cement, college trained engineers, and imported machinery. Items likely to become more available during the implementation phase are those that can be developed from locally available

resources as their need and potential for profit is recognized. These can include coconut husk rope used for well strainers, masons experienced in installation of water control structures, "in service" trained technicians, and locally manufactured tools. Solutions based on the latter types of physical facilities and manpower are likely to develop strength as they progress from the field trial to the implementation phases. Solutions based on materials and manpower in relatively fixed supply generally require associated programs to supplement supplies if they are to progress successfully into the implementation phase.

If the solution package is designed to drastically change production output, it should be determined if there is provision for adequate storage on or near farms to house increased outputs. It should also be determined if there is provision for transportation and processing of outputs, and whether markets have been verified for increased outputs.

Support services for irrigated agriculture can be organized entirely through government agencies; through private firms, although only rarely; or most often through a combination of government agencies and private firms. Typically, machinery and associated services including tractors and implements as well as tubewells and pumps are provided by private or quasi-public firms. If a new type of machine or implement is to be introduced, has the team verified that local mechanics can do the servicing? Is it, or could it be manufactured locally? If not, can critical parts be stockpiled? If training of local mechanics is necessary, has provision been made for this training?

If fertilizer inputs are involved in the solution package, is there a guaranteed supply at the national level? Is there a system of warehouses and transport suitable to guarantee timely delivery of good quality fertilizer to farmers? Are farmers familiar with fertilizer application? If not, are there adequately trained extension personnel to demonstrate fertilizer application? If not, has provision been made?

If a new crop variety is to be introduced, is there an extension network to monitor the crop for signs of vulnerability to disease or pests? Is the extension network designed to deliver suitable antidotes on short notice? Is there a means to guarantee quality of seed used?

If new structures are to be built on public water supply systems, is there provision to monitor and guarantee maintenance? This is

particularly important in regard to public tubewell pumps and outlet structures. Is there an inventory of replacement parts such as lubricants, fuses, gaskets, pipe sections, and patching cement. Lack of such parts can severely compromise the system and destroy crops. Will operators be trained to perform periodic maintenance and routine repairs? Will their superiors be able to monitor the work?

Organizational Structure

Presence of physical and human resources does not guarantee they will be used according to plans. For instance, managers are unlikely to take responsibility for monitoring maintenance of structures and machines if their authority and responsibility is not clearly defined.

Since timeliness is crucial in irrigation, there must be an ability to react quickly to farmer needs. Channels for communication both with local agency officals and with higher agency authorities will allow farmers to exert suitable influence on the services they receive. If farmers are illiterate or if they do not feel capable of communicating with high government officials, it is possible to use an advocacy system wherein an extension agent is legally authorized to act in the farmers' behalf, both with higher officials and with local functionaries.

Formal organizations can impede timeliness of function if decisions must be made at levels far removed from local problems. The ideal is decentralized decision-making with responsibility for monitoring extending up a chain of command.

If a solution package must include a new agency or a substantial change in an existing agency, it must be determined if sufficient time has been allocated for developing that organization. Hurried implementation of such a solution is likely to put managers of the newly-organized group at a disadvantage relative to other agencies or divisions of the same agency that compete for the same public resources.

Incentives for Job Productivity

Just as presence of resources is not sufficient to achieve goals, neither are existence of detailed plans and organizational structure sufficient to insure implementation of plans. The best organizations'

physical and human resources can fail to function effectively if objectives of individuals are not compatible with overall purposes.

It is tempting to assume that incentives follow lines of organizational authority and that they can be designed to work. However, incentives are only partly a function of the organization. The other parts come from individuals involved and from their social environment. The plan may call for an extension agent to spend more time in the field helping farmers with small landholdings. However, the agent's social background and education are usually closer to those of a few farmers with large acreage. Moreover, wealthy farmers are in a better position to secure help from an extension agent as part of reciprocal exchange, involving both material and social favors. Consequently, personal attributes, apart from technical expertise, can drastically affect the effectiveness of extension agents or other officials who deal with farmers. Use of attitudinal screening is a possible way for improving incentive structure. Another method of orienting the assistance more directly to the less educated farmers with small acreage is to use local persons with minimum education but more practical and field type training.

In some countries the government pays such low wages to its employees that they must gain additional income from some source to meet their responsibilities. One way in which the government employee can do this is to become so effective in the government position that the employee's services are in high demand and potential clients are willing to provide gratuities to obtain such services at an early date. While this is not acceptable in some societies, it may be an essential incentive for project success in others. Project staff developing a program should carefully research laws and how they are enforced because laws that are unenforced have, in many cases, been found to prevent incentives essential to the workings of the system.

At high levels adequate incentives may be more difficult to find. Often, middle level managers find field work distasteful or demeaning. One method for overcoming such a pervasive attitude is by example. If water management research personnel includes educated persons of recognized professional attainment, their eagerness to spend time in the field weakens the stereotype that educated persons do not become directly involved in field work. There is, however, no reason to

expect that the example of a few researchers will cause rapid change in deeply ingrained attitudes. Assessment of organizational capacity should therefore be based on a recognition of the existing incentive structure rather than on a desired change of attitude.

RESPONSIBILITY AND COMMUNITY SELF-DISCIPLINE IN WATER MANAGEMENT

Adequacy of the solution package in social, political, and legal terms must be assessed in the social, political, and legal frameworks of the country or area. Most of the developing countries have been under systems characterized as autocratic control by a central government. With the recognition of self-rule and democratization, some of these countries are attempting to replace central government control with local self-discipline and decision-making.

In some cases, local leaders are emerging who have strong interests in the common welfare, and recognition of the common interest is leading to self-discipline of a majority of the farmers, facilitating equitable distribution of resources to all concerned. In these cases, a solution package allowing the farmers flexibility to go in directions suited to their needs and take responsibility for the program is appropriate.

In other cases, relaxation of central control has resulted in a state of anarchy where each individual appears to be interested only in what he can extract from the system for himself. This leads to situations where farmers on the lower ends of watercourses are receiving little or no water and the distribution system deteriorates as farmers break the control structures and dig channels through the banks of distributaries to obtain water wherever and whenever they want. Such deterioration is often partly a result of a twisting of the democratization process in which newly-elected and immature representatives are used by these thieves to obtain exemptions from punishments for their misdeeds.

In some cases where self-discipline has not developed, and rapidly increased production is essential to the welfare of the country, the solution may require a return to government control with firm support of laws designed to provide equitable distribution of the water. However, this type of a solution results in additional costs for enforcement and tends to remove opportunities for development of self-discipline and local responsible leadership.

In any society, solutions that facilitate and encourage development of self-discipline and of local leaders who will work for the common good, will be the best long-term solutions. Such solutions will require educational and demonstrational components to enable participants to understand that the benefits to the individual of cooperative action for the common good will, in the long run, exceed the immediate and temporary benefits derived from selfish and illegal acts. In some cases, the water thieves are being allowed to permanently retain benefits derived from acts contrary to the common good. An essential component of the solution for such cases will be provisions for enactment and enforcement of laws to enable local leaders to restore the water resource to its rightful recipients and apply penalties to those who persist in actions damaging the common interests.

In assessing the potential for a solution to work in a framework that seems to border on anarchy, one needs to remember that even thieves have honor and intelligence and many such individuals are ready to change their ways if the new solution will improve their physical and social situations.

The reaction of the participants to the solution is often difficult to forecast. When field trials are conducted, and political and social problems prevent the solution from being completely effective, communication with the participants will often reveal underlying causes that can be alleviated by refinement of the solution. Immediate miracles should not be expected. Development is a step-by-step process. Replacement of an anarchic situation by a solution that still has some problems is a positive step, particularly if the new solution provides opportunities for understanding the benefits of self-discipline and for development and recognition of leaders who are working for the common good.

APPENDIX

USE OF LINEAR PROGRAMMING TO PRICE WATER

This appendix explains the basic idea of a linear program for crop selection/water pricing. The intent is not to give a rigorous mathematical or theoretical treatment. Rather the object is to introduce readers familiar with on-farm water management to the potential of linear programming.[1]

Rational management of water resources at the farm level presupposes knowledge of alternative strategies for allocating water to crops. In particular, there may be potential for combining crops whose peak irrigation demands are complementary, for selectively stressing some crops in order to stretch a fixed supply of water, and for substituting more or less water intensive crops for one another. Assuming that detailed knowledge about such strategies is available, the task of simultaneously considering all possibilities is formidable. Fortunately linear programming furnishes a convenient format for stating such problems so that they can be solved by readily available computer routines.[2] As a sort of bonus each optimal linear programming solution includes a set of "prices" which tells the analyst which constraints most strongly affect the value of the optimal solution.

An example will help to understand the use of linear programming for on-farm water management. The particular example used is a linear program constructed by the Colorado State University Water Management Research Project team for application to the Punjab in Pakistan.

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[1]Numerous texts are available for various aspects of linear programming. A standard general reference is Luenberger (1973). More specialized references dealing with agriculture are Agrawal and Heady (1972) and Beneke and Winterboer (1973).

[2]Most major computer companies (e.g., IBM, Control Data, Univac) have special mathematical programming systems and some desktop computers also have linear programming packages (e.g., Hewlett Packard).

CROPPING ACTIVITIES

The basic building blocks of the crop selection linear program are cropping activities. These are just a summary of the inputs to and outputs from an acre[3] of a given crop. For example, an acre of wheat needs an acre of land from November through April, it needs fodder for animals used in plowing, it needs labor during two busy periods of the year (April-May and October-November), and it needs irrigation in four months: November, December, February, and March. This information can be displayed as a budget:

Yield = 30 maunds:

Water

December:	4 acre inches at the root zone
November:	3 acre inches at the root zone
February:	3 acre inches at the root zone
March:	3 acre inches at the root zone

April-May labor: 20 man hours

October-November labor: 20 man hours

Summer fodder: .1 units (acres of maximum yield summer fodder)

Winter fodder: .15 units (acres of maximum yield winter fodder)

A table can be used as a shorthand for summarizing many such cropping budgets. The columns of the table are the cropping activities, while the rows of the table are the inputs and outputs. For example, Table 9 has been constructed using wheat along with cotton, summer fodder, sugar cane, rice, and winter fodder.

Although it should be clear how most numbers were arrived at for wheat, there is a need for explanation on several points. First of all, the first row is net revenue and it is treated differently from other rows. It is just: (yield x market price) - (cash costs). In the case of all but fodder crops the value is assumed to be positive. Fodder

[3]The acre unit is arbitrary; the unit could be chosen as a hectare or a "square"__. Acre is used as a common unit for measuring crops.

Table 9. Example of cropping activities.

		Cotton	S. Fodder	Sugar Cane	Rice	Wheat	W. Fodder
Net Revenue		$281.50	-$200.00	$538.00	$335.00	$563.00	-$200.00
Water:	May	1.36	2.86	8.36	7.36		
	June	2.73	6.23	7.73	6.73		
	July	3.94	4.44	5.94	9.94		
	September	3.73	5.73	4.73	6.73		
	October	2.90		5.90			
	November	3.00		9.00		4.00	3.00
	December			6.00		3.00	3.00
	January						
	February			3.00		3.00	3.00
	March			5.00		3.00	3.00
	April			8.00			6.00
Labor:	Apr-May	20	15	20.0	25.0	20.0	15.0
	June-July	15	30	20.0	45.0		
	Oct-Nov	30	15	20.0	20.0	20.0	15.0
Land:	Summer	1	1	1	1		
	Winter					1	1
Fodder:	Summer	.15	-.85	.15	.15	.1	
	Winter	.15			.05	.15	-.85

crops are assumed to be a requirement of other crops (feed for bullocks) and not marketable. Therefore, fodder has only a cost and no direct revenue.

The remaining rows have a different sign convention from that used in the net revenue row--all inputs appear as positive numbers, all outputs appear as negative numbers. Therefore, the fodder activities produce a net of .85 acres of high yielding fodder per acre cropped (.15 units are used as the fodder required to plow the land for raising fodder). Other crops differ in their net fodder requirements according to whether that crop has a by-product used as fodder (e.g., rice, wheat, and sugar cane).

Water use entries in the table have odd amounts in the summer months because rainfall has been subtracted from the requirement for water at the root zone in each month.

WATER DELIVERY ACTIVITIES

There are several ways to handle water supply. One is to simply specifiy an amount of water available in each month.[4] In doing so one must always be careful to see that water requirements and water supply are specified in the same unit, in this case, acre inches at the root zone. The method used in this particular model was a single water delivery activity which made available the same amount at the root zone in every month, and which was limited by a "capacity" restraint. This had the advantage of being close to the real water supply situation in the Pakistan Punjab: surface water was available in fixed amounts in each month, with no cost associated with use of water (aside from a land tax). Another advantage of using a capacity constraint is that its price gives a summation of the values of water in each of the water supply periods.

Alternative supply activities might be inclusive of a tubewell supply for supplemental water. Tubewells are subject to a variable cost of pumping and should be specified separately for each period. For

[4]Initial stocks of resources are usually entered in a special column at the left of a linear programming table. See Table 10 for an example.

example, a tubewell activity that supplies one acre inch of water in March would have a negative entry in the net revenue row, a "-1.0" in the March water row, and "1.0" in a special row which sets a limit on the water which can be supplied by the tubewell. Again, it is important to be sure that supply is in the same terms as demand. If, for example, irrigation application efficiency is 85 percent, then the number entered in the March water row is -.85 acre inches at the root zone to every acre pumped. Or, alternatively, the number in the March water row could be -1.0 at the root zone which the cost of pumping the necessary water which would be the cost of pumping an acre inch divided by .85.

CROPPING ACTIVITIES WITH PLANT STRESS

So far no mention is made of how water demand coefficients are derived for cropping activities. Those demands given in Table 9 represent the no-stress levels of irrigation for the Sarghoda area of the Pakistan Punjab, given "average" weather and existing "average" husbandry practices. But actual irrigation strategies are likely to be more sparing with water due to shortages in key months. Therefore, it is well to estimate yields and returns for strategies which attempt to adjust irrigations to accommodate peak demands on water. Table 10 contains an elaboration of Table 9 for water stress activities. For example, the non-stress wheat activity used 4 acre inches in November, a month in which water is often limiting. Another activity, wheat 3, is defined as using 3 inches in November and none in January and February. The resulting yield is 80 percent below that of the non-stress activity (wheat 1). Two other activities are specified: wheat 2 which has milder stress and which gives 90 percent of maximum yield and wheat 4 which uses no November irrigation, is significantly stressed and which gives 60 percent of the maximal yield. Similar treatments have been given to the other crops in Table 9, using data from Pakistan.

The important point is not the origin or precise forms of the stress inducing strategies, rather it is that such activities need to be represented in a linear program in order to represent the real economic choices facing farmers in their alternative irrigation strategies.

Table 10. Example of cropping activities influenced by water shortages.

	Resources	Cotton 1	Cotton 2	Cotton 3	Kh. Fodder 1	Kh. Fodder 2	Kh. Fodder 3	Kh. Fodder 4	Sugar cane 1	Sugar cane 2	Sugar cane 3	Rice 1	Rice 2	Rice 3	Wheat 1	Wheat 2	Wheat 3	Wheat 4	R. Fodder 1	R. Fodder 2	R. Fodder 3	R. Fodder 4	Leavery
Net revenue		+281.5	+245.5	+200.5	-200.0	-180.0	-175.0	-175.0	+535.0	+438.0	+378.0	+335.0	+285.0	+245.0	+563.0	+492.0	+430.0	+369.0	-200.0	-180.0	-175.0	-175.0	
Water, May		1.36	1.36		2.86	1.86	1.36	0.36	8.36	6.36	4.36	7.36	5.36	3.36									-1
Water, June		2.73	1.73	1.73	6.23	2.73	1.73	1.73	7.73	5.73	3.73	6.73	4.73	3.73									
Water, July		3.94	2.99	0.94	4.44	1.94	0.94		5.94	3.94	1.94	9.94	6.94	4.94									-1
Water, Sept.		3.73	2.73	1.73	5.73	2.73	1.73	0.73	4.73	2.73	0.73	6.73	4.73	2.73									-1
Water, Oct.		2.9	1.9	1.9					5.9	2.9	1.9												-1
Water, Nov.		3.0	2.0						9.0	6.0	3.0				4.0	4.0	3.0		3.0	3.0		3.0	-1
Water, Dec.									6.0	3.0	3.0				3.0		3.0	3.0	3.0			3.0	-1
Water, Jan.																3.0				3.0			-1
Water, Feb.									3.0	3.0					3.0	3.0		3.0	3.0			3.0	-1
Water, March									5.0	3.0	3.0				3.0	3.0	3.0		3.0	3.0	3.0		-1
Water, April									8.0	5.0	3.0								6.0	6.0	3.0	3.0	-1
LBR April-May	13000	20.00	20.00	20.00	15.00	15.0	12.0	12.0	20.0	18.0	16.0	25.0	25.0	20.0	20.0	20.0	16.0	16.0	15.0	15.0	12.0	12.0	
LBR June-July	6000	15.00	13.00	13.00	30.00	30.00	24.0	24.0	20.0	20.0	16.0	45.0	40.0	35.0									
LBR Oct.-Nov.	1500	30.00	30.00	25.00	15.00	15.0	12.0	12.0	20.0	20.0	18.0	20.0	18.0	15.0	20.0	20.0	20.0	20.0	15.0	15.0	12.0	12.0	
Land, Kharif	500	1	1	1	1	1	1	1	1	1	1	1	1	1									
Land, Rabi	500								1	1	1				1	1	1	1	1	1	1	1	
Fodder, Kharif	-35	+0.15	+0.15	+0.15	-0.85	-0.8	-0.75	-0.7	+0.15	+0.15	+0.15	+0.15	+0.15	+0.15	+0.1	+0.1	+0.1	+0.1					
Fodder, Rabi	35	-0.15	-0.15									-0.05	-0.05	-0.05	-0.15	-0.15	-0.15	-0.15	+0.85	+0.80	+0.75	+0.70	
Capacity	750																						-1

Certainly the idea of diminishing returns to additional water application is familiar to economists who understand that the maximum yield solution is seldom economical if water is scarce. It is precisely this idea that can be captured by specifying alternative activities for each crop.

USING LINEAR PROGRAMMING PRICES TO VALUE WATER

As mentioned earlier, every optimal solution to a linear program has a set of associated "prices" which correspond to the resources or contraints of the problem. In the crop selection problem, prices have a straightforward and economic interpretation: they indicate the value to the optimal solution of their associated resources. For example, if the solution "price" of March water is Rupees (Rs.35), this means that an added acre inch of water available in March would result in an increase of Rs.35 in the optimal value of the problem. Or put another way, if one were to consider removing one acre inch of water from the farm in March, its opportunity cost to the farm would be Rs.35.

These prices give at least two important indices. The first is the relative importance of water in different periods. Typically, only 3 to 5 water constraints will be totally used in any optimal solution. This means that other supplies will be excess and therefore assigned a zero value. In fact, if there were another region (or farm) whose seasons (or crops) differed, it might be that excess water could be profitably traded between regions (farms) (assuming no costs of transportation or transactions). Or, it could be an indication that storage is in order--(use of tubewells in conjunction with surface water is one type of storage).

Another index is the sum of the prices on water restraints. This is a measure of the value of the overall delivery capacity It can be used to judge the value of changes such as addition of tubewells, improvement of delivery efficiency of watercourses, or increased application efficiency. Clearly, the pricing feature of linear programming is a useful way to estimate benefits for various changes in on-farm water management. But is must be emphasized that diminishing response of crops to added water is important in predicting benefits.

In the absence of reliable information on water response functions, what does the analyst do? One common practice is to use farm budget

information and thereby define alternatives in terms of existing practices. This should lead to reasonably good results in getting a linear program to duplicate solutions used by farmers. But it does leave the analysis vulnerable to error when water resources are to be expanded outside the limits of farmers' experience. There will probably be a tendency to undervalue increases in water supply because the strategies represented do not reflect the potential returns to changing irrigation practices in order to reduce stress.

A NOTE ON DETAIL

In building water pricing programs it is important to choose appropriate periods for water availability. Usually one month intervals are sufficiently detailed to capture the seasonal aspects of water demand. But it may be that shorter periods are necessary during particularly intense periods of demand. For example, the period before spring planting in the Pakistan Punjab has an intense demand for irrigation due to the need for pre-planting moisture in seed beds. Monthly water constraints used in the example presented in Table 10 have tended to aggregate out the most intense shortages and therefore understate the value of water in the spring planting period.

Care should be exercised so that too much predictive power is not attributed to linear programming solutions. Changes in "farm management" practices may entail reallocation of numerous resources including labor, tractor power, and capital. Moreover, learning is often required. The crop selection/pricing linear program is ill-equipped to predict rates of learning or rates of adoption when farmers must reallocate their resources within a complex environment, only part of which is represented in the linear program. This is not to say that a precision leveled field cannot be represented in a linear programming problem to check effects on shadow prices of various inputs. But, the model should not be presumed to predict rates of adoption of the precision land leveling innovation.

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