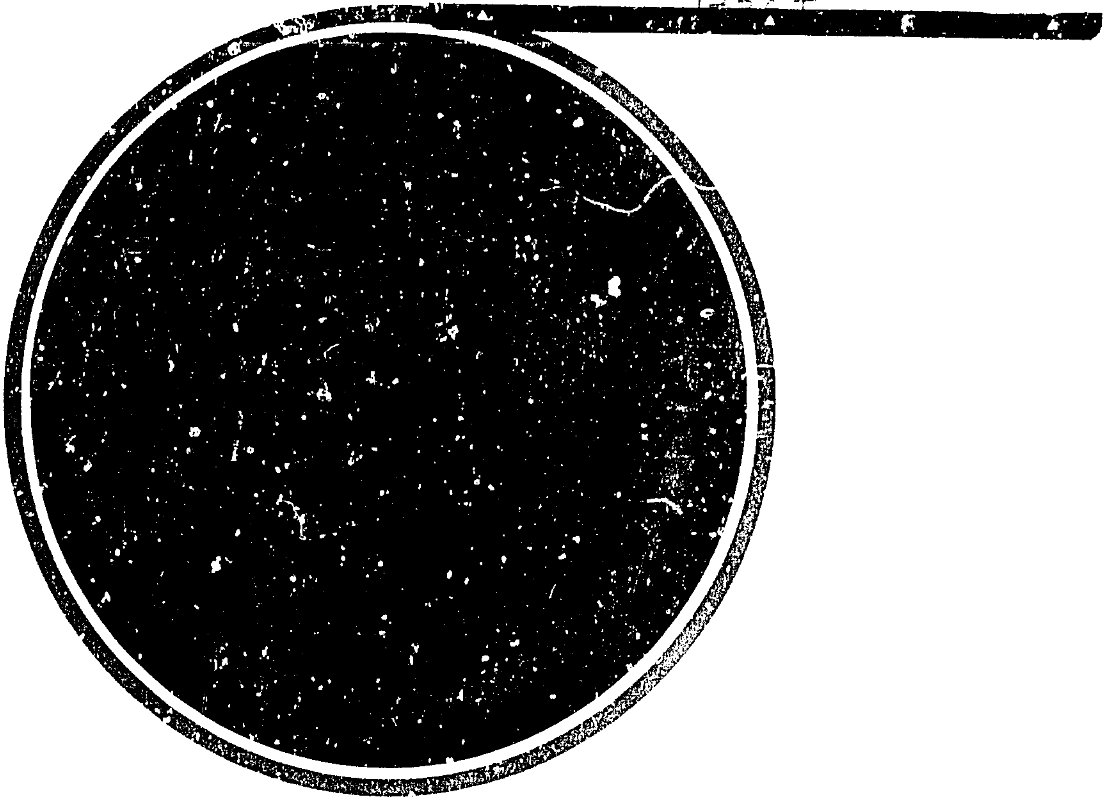

SMALL-SCALE IRRIGATION: DESIGN ISSUES IN GOVERNMENT-ASSISTED SYSTEMS

WATER MANAGEMENT SYNTHESIS II PROJECT

WMS REPORT 39

SMALL-SCALE IRRIGATION:

Design Issues in Government-Assisted Systems

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Preface

This paper was prepared with suppport from the Water Management Synthesis II Project (WMS-II), and owes much to formal and informal discussions with Cornell's Irrigation Studies Group. The paper began as a draft discussion paper for a workshop at Cornell in November 1983, attended by representatives from irrigation agencies, donor agencies and research groups from the US and around the world. In addition to drawing upon our own experience, we surveyed the literature. Various members of the group made field visits to countries with significant small-scale irrigation experience. Our paper draws on ideas from all these sources.

We would like to acknowledge the support of Ray Norman, E. Walter Coward Jr., Barbara Lynch, Bob Yoder, Ed Martin, and the many others who commented on the early drafts and raised many important issues, Beth Rose who patiently edited the paper, and Betty Van Amburg and Fu'a Hazelman who typed several drafts.

Executive Summary

Large-scale, government-assisted irrigation systems have usually adopted a conventional approach to development. The conventional approach follows a formal top-down pattern with most major design decisions made by government agency professionals who create a master plan for the system. Government interest in assistance to small-scale irrigation is relatively new although small-scale irrigation systems represent a major portion of the total irrigation command area in many countries. These small-scale systems have by and large developed through an evolutionary process, a pattern that has apparently followed an informal, bottom-up mode with development taking place in incremental steps in response to lessons learned from trial and error experience. This paper examines issues and opportunities related to government technical assistance to small-scale irrigation development.

In most cases, where governments design small-scale irrigation systems, there appears to be a tendancy to use a conventional approach. Because of insufficient site-specific data and other limitations, the direct application of the conventional design approach is unsatisfactory for small-scale design. Further, governments are becoming aware of many of the positive characteristics of locally developed systems and would like to see these characteristics in projects in which they are involved. A compromise between the conventional and evolutionary approaches is needed that will satisfy the operational requirements of governments (and donor agencies) and still include a sensitivity to local control, which sustains and makes small-scale irrigation systems perform well.

We have approached the issue of government assistance by first examining changes in the conventional approach that would make it more appropriate for small-scale systems that are to be locally controlled and operated. We have called this government small-scale design conventional approach. We also have considered opportunities for external technical assistance to the local development pattern, and this has been termed government small-scale design evolutionary approach.

Among the important issues that we feel should be considered for government involvement in small-scale irrigation development patterned after the two scenarios are the following:

Conventional approach

1. Local participation in project identification must be increased, perhaps even requiring that projects be considered for implementation only if proposed and requested by the farmers.

2. Data available for small-scale design are not appropriate or available in sufficient quantity for the vigorous data-intensive engineering analysis techniques used in large-scale irrigation design. Local people can be a valuable source of design information if methods could be found to translate their knowledge into quantifiable design parameters.

3. It may be more appropriate to evaluate the type, quantity, and quality of data available for an irrigation system and to select design analysis techniques based on available data rather than to use inappropriate or inadequate data with predetermined design procedures.

4. Conventional preliminary designs are usually based on technical analysis done primarily by engineers. This preliminary design creates a framework for a system master plan that may lack the necessary flexibility to make adjustments in response to new data or other than technical considerations. Rather than preliminary designs, a concept of system architecture might be followed where the architecture emphasizes the inputs from many disciplines and the final decisions are made by the local farmers. The degree of flexibility to make changes in the system architecture once it is determined will generally be dependent on the prevailing government operational constraints.

5. The individual structures of an irrigation system have been termed components. The objective of component design is to make the structures (including on-farm water utilization techniques) effective and cost-efficient. Analysis techniques that require limited site-specific data and that result in designs that can be built with local resources are lacking and need to be developed. In some cases, standardized component design seems to be an appropriate approach to overcome limitations in availability of site-specific data and engineering expertise, although must be employed cautiously.

6. Designing for irrigation water-use efficiency needs to be assessed in comparison to other concepts, such as design for equity.

7. Small-scale systems are often constructed by local contractors who lack necessary skills and experience. The advantages and disadvantages of construction by the local sector should be addressed on a case-by-case basis. Upgrading the skills of local contractors to assure quality control should be undertaken within the framework of the project, where necessary.

Evolutionary approach

1. Experience in providing government technical assistance to locally-owned and controlled irrigation systems is sparse, with perhaps the exception of programs in northeast Thailand and the Philippines.

2. A model that might provide the basis for government assistance to local irrigation development is that of the US Department of Agriculture, Soil Conservation Service program, appropriately tailored to local conditions.

3. The investment per project required to stimulate local development is low if investments are made in a system only when farmers are prepared to make use of them. The technology employed may be rudimentary, but will generally reflect the optimum economic efficiency from the farmers' perspective.

4. More needs to be known about the time period required for farmers to develop the confidence and skills necessary to operate irrigation systems at full potential.

5. Care must be exercised in determining the level of assistance that can be given to small-scale irrigation development to avoid negating the indigenous motivation that drives the local approach and also avoid an imbalance in the local environment.

6. External assistance for technology transfer seems appropriate and potentially effective for improving systems developed following the local pattern. However, the most appropriate technologies may not be those that are modern, but rather proven traditional technologies from other locations.

The nature of these issues suggests that there is considerable scope for further research. Moreover, the challenge and focus of this research will undoubtably be learning how to use existing technology more effectively in a practical field setting. An equally important aspect of further research will be to provide active channels of communication between researchers, and to encourage publication of studies and results.

Introduction

Assistance from national or regional governments and external aid agencies to irrigation system development has often been in the form of investment in large-scale, centrally administered systems. Only recently have government irrigation agencies shown interest in small-scale systems. In most cases small irrigation systems have been built by farmers themselves. A rich variety of community-based indigenous technologies and organizations have evolved for water management including, for example, the subaks in Bali, the extensive hill irrigation systems in the Philippines and Nepal, and the traditional garden irrigation in the Sahel (Geertz, 1980; Bagadion et al., 1980; Martin and Yoder, 1983; Moris et al., 1984). In fact, an extremely wide range of small systems are found in almost all parts of the world, both developed and developing. Recent field studies of some of these indigenous small-scale systems have increased our understanding of how these systems evolved. Since government involvement in small-scale irrigation is a comparatively new idea, proven approaches to government involvement in design of such systems are not generally known. In this paper, we divide small-scale system development into two broad categories:

(1) Conventional. Based largely on experience gained from the engineering design of large-scale irrigation systems, this mode of development is typical of projects with direct government supervision.

(2) Evolutionary. This approach is typical of systems developed through local initiatives to meet local needs, usually without outside financial and technical assistance. These systems are developed through an interactive process: they are continuously altered and adapted to changing irrigation

needs. The evolutionary approach to design is common among viable indigenous systems and what are frequently referred to as "traditional" irrigation systems.

Governments have concentrated on large irrigation systems in the past in part because of a desire to utilize the most advanced state of the art engineering technology and presumably to make the greatest possible use of limited technical expertise. However, large-scale system performance has generally been well below expectations (Steinberg et al., 1983). This is partly due to the wholesale transfer of "modern" engineering technologies from developed countries, with little accommodation made for local agronomic practices and socioeconomic conditions.

Dissatisfaction with large-scale system performance and a growing awareness of the wealth and extent of indigenous irrigation experience that is typically small-scale has prompted governments, donor agencies, and lending institutions involved in irrigation development to review successful small-scale experiences in the hope of developing a format to promote the growth of small-scale systems. The extent of use of small-scale irrigation is perhaps much greater than one might expect. A recent report for the state of Himachal Pradesh, India (USAID, 1984a) indicates that over half of the state's 136,000 ha. of irrigated area are served by small community systems. In the Philippines, 51 percent of the area irrigated is served by "communal" systems (Valera, 1985). A similar pattern is found in many other parts of the world. Small-scale systems cover a wide range in which varying degrees of control are assumed by a central administration and by the irrigators served by the system.

Where irrigation is an important resource, government agencies usually exist to coordinate and manage activities within the irrigation sector. Such agencies vary from country to country, but are usually part of the ministries of public works or agriculture. Generally, irrigation agencies are staffed by civil engineers and are primarily responsible for large-scale, centrally administered systems. In many instances, these agencies are also responsible for promoting activities within the small-scale sector. Their mode of operation is an important determinant of how publicly supported, small-scale development occurs, and therefore the bulk of our discussion focuses on the processes used, and the constraints confronted by these agencies in performing their technical missions. In some cases, the responsibility for the small-scale sector is assigned to other agencies or departments such as agriculture or rural development. These departments often lack the engineering expertise necessary to design and operate irrigation systems. In a few cases, development aid is given directly to farmers or a local community with little or no design assistance. This is the situation for some private well development schemes, for example.

Because most small-scale irrigation has evolved indigenously, relatively little published technical literature exists on the subject of engineering assistance, although a growing body of literature is found in the social sciences. In general, government assistance to small-scale projects appears to involve scaled-down versions of the same procedures used in the design of large-scale systems. This approach has many limitations, and this paper takes a fresh look at engineering options for government assisted small-scale systems development.

Definitions

We broadly classify irrigation systems into four technology groups: (1) surface irrigation systems that deliver water under gravity in defined conveyance channels; (2) groundwater systems that require a lifting device to raise water from the source to the field; (3) flood irrigation systems, where flood waters maintain a desired water level in the field; and (4) manual irrigation involving micro-lift schemes. Small-scale systems are included in all of these groups. In practice, a mix of several technologies is common. For example, in South India, surface water stored in tanks is used early in the crop season, but farmers use shallow wells to irrigate their crops after the surface source is exhausted (Meinzen-Dick, 1984). A similar situation exists in the Mullala Project in the Maggia Valley in Niger where surface water is used in the wet season, but well water largely supplied by seepage from the system reservoir is used in the dry season (Walter, 1985). Water supplied to an irrigation command area from both surface and groundwater sources is commonly referred to as conjunctive.

Surface water systems may be termed storage or non-storage systems. Non-storage systems (also called diversion systems) generally make use of the available flow in a river during the irrigation season, whereas a storage system may provide reservoir capacity for the short term, for a season, or even over several seasons. The zanjeras in the northern Philippines (Lewis, 1980) provide a good example of diversion systems, and the "tank" irrigation systems in Sri Lanka (Leach, 1980) are examples of storage systems.

In contrast to surface water systems, groundwater systems depend on water stored in an aquifer below the surface of the ground. The water table may be close to the surface and relatively easily tapped (e.g., the hand-dug wells in West Africa using the shaduf and the "shallow" tubewells in Bangladesh with a small surface-installed motor and pump lifting water under suction), or at greater depths requiring more sophisticated lifting techniques (e.g., the deep, drilled wells in the Sahel used to tap fossil water beneath the surface). Development of groundwater sources for irrigation has increased rapidly in recent years, but is often hampered by a lack of local repair skills, maintenance facilities, spare parts, and fuel or access to electric power for the lifting devices (Campbell, 1983; Moris et al., 1984).

Moris et al. (1984) distinguish flood irrigation from other types in terms of the degree of water control for irrigation. In practice, total control is rarely achieved in any irrigation technology, but flood irrigation results in partial control at best. Flood irrigation is practiced extensively along the major rivers in West Africa and elsewhere. The rise and recession of flood waters are controlled by embankments, submergible dikes, and sluices, allowing crops such as deepwater rice to be grown, followed by a dry season grain crop. Flood plain irrigation without dikes may also be considered in this category, as well as depressional irrigation (bas-fonds in West Africa), which relies on a rising water table.

Manual irrigation, used for production of high value market crops or household gardens, can be found in almost every irrigated area. For example, in Mali and Niger, farmers have relied on manual irrigation to produce a high value onion crop. In recent years there has been considerable interest in the design of manually operated pumps appropriate for small-scale irrigation (Hanratty, 1983; Moris, 1984).

There are wide differences in the technologies employed in irrigation systems throughout the world. Locally initiated irrigation development typically makes use of local materials and experience. Conversely, conventional irrigation projects generally utilize "modern" technologies which are based on recent engineering research and rigorous design practices (although these too may have their roots in traditional technologies and practices).

As mentioned previously, government assistance to irrigation in the past has primarily been directed toward large-scale systems. However, governments are beginning to recognize the importance of community systems in the irrigation sector. They would also like to transfer to larger systems in which they are involved some of the characteristics of traditional small-scale systems that cause them to be efficient, productive, sustainable, and locally maintained.

Two main elements must be considered by agencies involved in the design of small-scale irrigation. First are the issues related to the size of the system. In particular, government agencies have limited technical expertise that will need to be spread out over more systems with the small-scale approach. Second, and perhaps more important, is the goal of encouraging and replicating the positive performance characteristics commonly found in indigenous systems.

Government assistance is needed to varying degrees in order to stimulate small-scale irrigation development. This includes funding support by external donor agencies. The degree of government assistance used for small-scale irrigation development will vary from one country or situation to the next. One extreme is to provide no government technical assistance but some measure of financial and institutional assistance (see Coward, 1984). The other extreme is a conventionally designed "turnkey" system—a system conceived, designed, and constructed by an agency with no local input and turned over to a group of farmers upon "completion." We believe that a compromise between these two extremes will in many cases result in small-scale systems that perform well, meet the government and/or donor agency constraints and requirements, and improve the well-being of the local community. In the following discussion, we describe both conventional and evolutionary approaches to irrigation development and then consider blends of the two that exploit the strengths of each.

Conventional Large-Scale and Evolutionary Small-Scale Development

A comparison of approaches to conventional large-scale and evolutionary small-scale development show a remarkable difference between the two. Large-scale irrigation development usually follows a top-down approach, with all major and early decisions made by government agencies with very little predesign or preconstruction involvement of local people. A formal "master plan" is decided upon that is based partially on an engineering feasibility study. The master plan defines the extent of the physical infrastructure and the schedule for project construction in a fixed time frame. Physical system infrastructure and structual component design are based on sophisticated techniques that are typically highly data-intensive and usually require the skills of degree-holding engineers.

In contrast, most small-scale irrigation development is usually locally initiated, occurring in a bottom-up and informal manner. There is generally no apparent master plan for these systems. Rather they evolve incrementally in what might be considered an "organic" fashion. Over time, local experience gained from working with the physical and organizational aspects of the system contributes to future operation and management practices. Water users may continuously improve and adapt the system in response to successes and failures. An interesting example of local system development is the Chherlung Thulo Kulo Irrigation System in Nepal, described by Martin and Yoder (1983b: 2-3, 14).

> Two persons with land in Chherlung took the responsibility to raise money for building the canal. . . Construction work was begun in 1928 and continued for ten months each year. Water was first brought through the length of the canal in 1983. . . The initial cut of the canal was small and only brought enough water for a few fields, but it proved to all the skeptics in the community that water would run the 6.5 kilometers through the rugged jungle and through tunnels and channels cut into vertical cliffs. Work proceeded immediately to enlarge the canal. . . Thulo Kulo has been improved on almost a yearly basis. Tunnels and sections cut into rock have been enlarged and leakage has been controlled by lining short stretches. . . The system has expanded from 32 to 105 members since 1932 and now covers nearly all of the potential khet land (34 hectares). . . The expansion of membership and area served is directly related to the increased water availability through improvements to the system.

It is also worth noting that on three occasions, beginning in 1967, the District Panchayat made small grants for the improvement of the system. The authors also suggest that "this incremental approach to improvements has allowed concentration of resources on the weakest segment of the system each year, and maximized the use of local labor."

Although small-scale system evolution usually takes place through a series of many small improvements over a long and undefined period of time, occasionally relatively major inputs will be required such as the construction of new headworks or a main canal.

Figures Ia and Ib represent schematically the pattern of development that might be expected from conventional and evolutionary approaches, respectively. The bold lines in these figures represent the system potential, and the finer lines the actual utilization. (We assume that Figure I would represent conventionally designed, small-scale irrigation development, although we have very little experience to support this.) Since conventional development has been primarly large-scale and traditional development small-scale, Figures Ia and Ib might equally illustrate past patterns for large- and small-scale development.

In Figure Ia, the bold line from points I to 2 represents the construction or implementation phase of development. For surface systems, the headworks are built first. This typically represents about 50 to 75 percent of the total system construction costs. No potential for utilization exists until the distribution canals are built, but this usually occurs relatively rapidly. System utilization (i.e., construction of tertiary canals and on-farm development by farmers) follows the fine line. For large systems, the time period between points I and 2 is normally five to ten years, and for small systems, one to two years is anticipated. In actual practice, some large-scale systems have taken twenty or thirty years to construct. Although the slope of the bold line between points I and 2 and the fine line between points I and 3 are often "planned" to be nearly identical they rarely are. Instead, actual utilization increases slowly at first and accelerates as farmers and

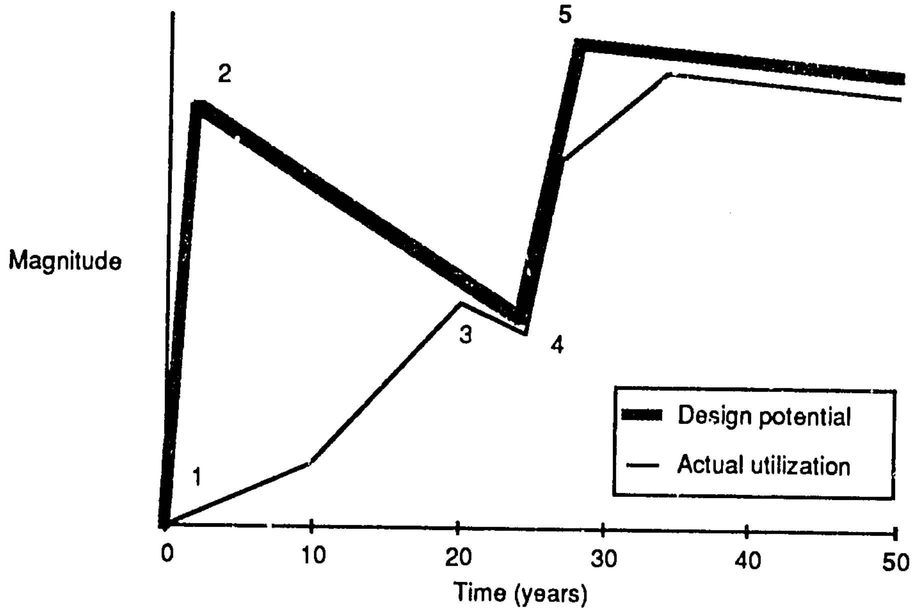

Figure 1a - Schematic conventional approach

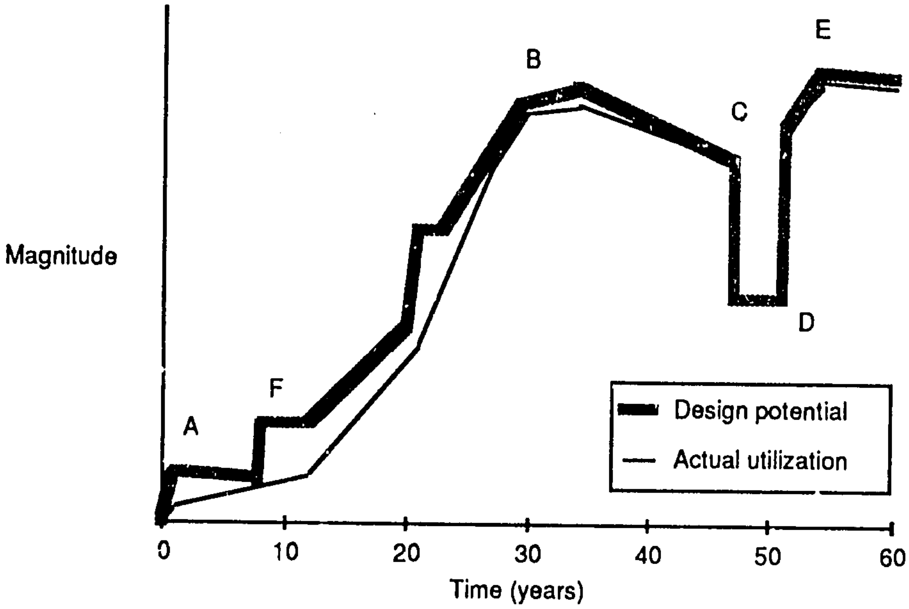

Figure 1b - Schematic evolutionary approach

Figure 1. Rate of irrigation system development for design potential and actual utilization

agency staff learn to manage irrigation and operate the system. External assistance can theoretically decrease the operational gap between potential capacity and actual utilization by providing training, demonstration, and support services. However, development of human skills and attitudes is a slow process, even with outside assistance. We also note that system design potential is based on data and assumptions that may not themselves be correct, in which case actual utilization will be unlikely to match the anticipated design potential.

The line between points 2 and 4 in Figure la illustrates a typical degradation of system infrastructure. This decline is fairly rapid because initial system utilization is often low, and consequently there is little pressure to operate at full design potential. Also, there may be a poor understanding of how the designers intended the system to be operated. At some point, illustrated by point 3 in the schematic, utilization matches the (degraded) system's ability to deliver water. It is at this point that rehabilitation should be considered. (In the illustration we are considering only physical rehabilitation, although we recognize rehabilitation included many other aspects as well.)

Ideally, rehabilitation design should be based on experience gained over the life of the system. In this case, the "design" potential at point 5 after rehabilitation may be different (higher or lower) than that at point 2. After rehabilitation, utilization should quickly return to pre-rehabilitation levels, and continue to increase. In theory, system degradation after rehabilitation should be much slower than before because the design is more suited to local conditions and utilization should more nearly match design potential.

In Figure lb, which shows evolutionary development, several significant differences can be seen compared to the conventional approach illustrated in Figure la. The rate of potential irrigation development, bold line A to B, is much slower than that of l to 2. However, utilization and potential lines more nearly match for evolutionary development, which indicate more economically efficient systems. Major incremental jumps in the system potential, as shown at point A or F, result from relatively major improvements (e.g., new headworks or main canal) in the system. The rate of deterioration of traditional systems (B to C) is comparatively slow because the systems tend to fit site-specific conditions and resources, and actual utilization is constantly putting pressure on the system potential. Point C shows that small systems can suffer rather significant setbacks in their potential due, for example, to major flooding damage to headworks or to loss of a main canal because of landslides. In fact, some disasters completely destroy system potential, at least for a time. External technical assistance might be particularly useful where major new infrastructure is needed to expand or rebuild system capacity.

For the conventional approach to be effectively used for small-scale development, processes and procedures need to be developed that bring the rate of increase of system utilization more in line with design potential. This requires fundamental changes in organizational structure to reduce the rate of project implementation through conventional development in the way limited technical expertise is used, and in the construction process. These, and the necessary changes in human skills and attitudes, are difficult to achieve in the short term.

Government assistance to local systems, on the other hand, must be carefully thought out to retain the successful, self-sustaining characteristics of traditional systems. For example, ways must be found to overcome the long periods of development that characterize indigenous systems. Experience in the Philippines and Thailand indicate, however, that considerable potential exists through the use of technical and financial assistance, in cooperation with project beneficiaries, to achieve greater and more rapid utilization of small-scale system potential.

In summary, the blending of conventional and evolutionary development approaches to irrigation design for small-scale, government-assisted systems can be broadly viewed in two ways. One option would be to use the basic design framework for conventional irrigation systems, overlaid by indigenous design elements. The alternative approach is to use an indigenous or traditional mode of design while incorporating modern technical techniques and technologies.

Conventional Engineering Design Process

Figure 2 includes six stages that are typically used in conventional engineering development. One might argue that these same stages are used informally in indigenous, evolutionary irrigation system development. The procedures used at each stage would be quite different for evolutionary development as compared to conventional design. However, the fundamental difference between the two approaches is that with the conventional approach, the tasks illustrated in Figure 2 result in a blueprint master plan based on information at the start of the project.

With the evolutionary or iterative approach, the process is continually repeated as trial and error experiences produce new information.

The stages of Figure 2 conventional irrigation system development plus evaluation and rehabilitation are briefly described below. The inputs and outputs at each stage provide a useful means of defining the activities performed within each stage.

Project Identification. The first and probably most critical step is a determination of the need for an irrigation project in a given area. In government programs, the selection of an irrigation project is based on criteria that meet predetermined government objective(s). Objectives might include increasing the

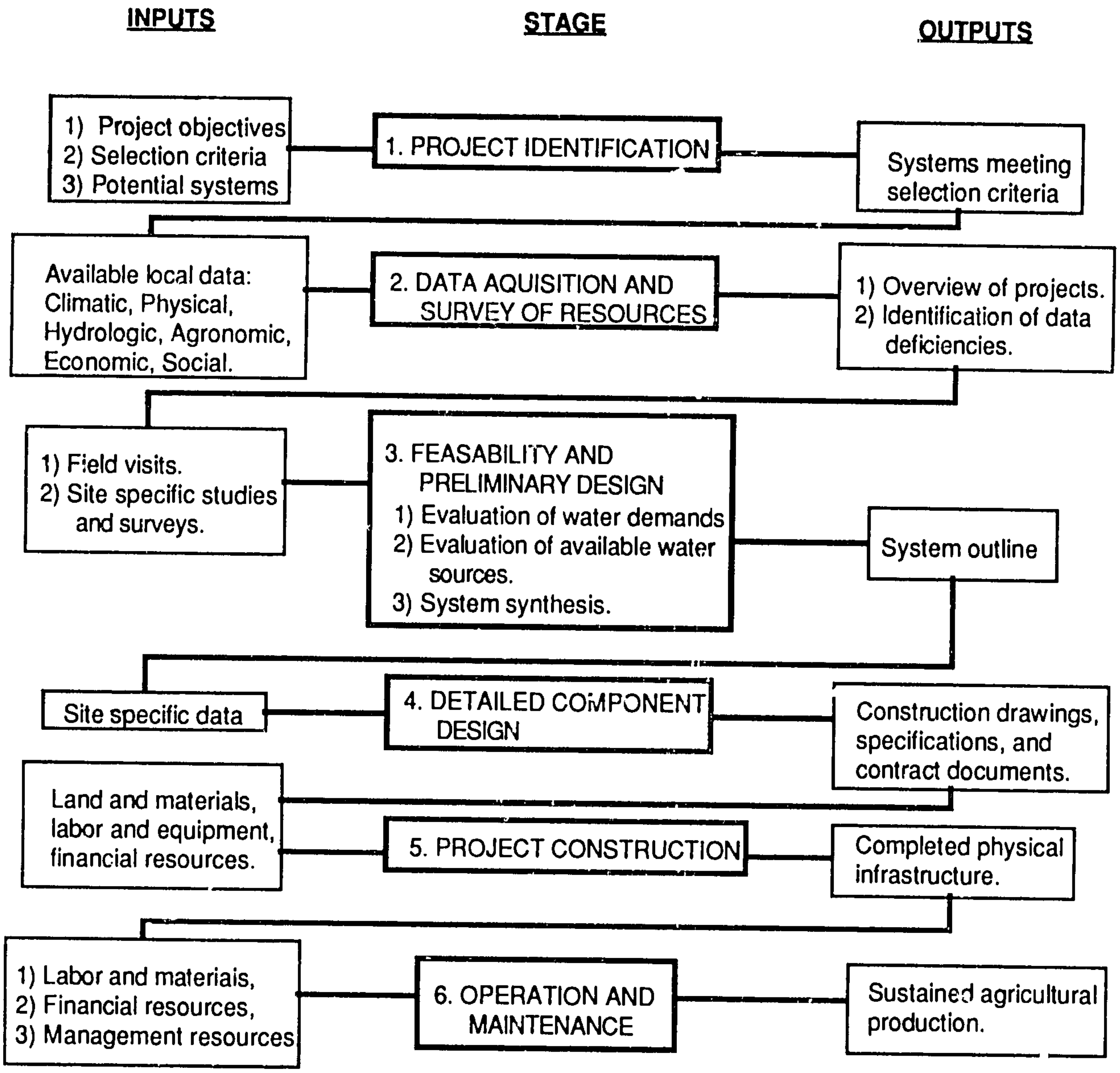

Figure 2. Basic stages of conventional technical development of an irrigation system.

food supplies or production of critical foodstuffs such as cereal grains, settling people in selected regions of the country, reducing migration to urban areas, protection against drought periods or improving the well-being of an area's people. These may or may not be consistent with farmers' objectives. Within a project, selection of specific sub-projects for implementation is often based on criteria of physical and economic efficiency. Many initially identified systems do not meet selection criteria because of scanty data, but this can be determined only at the conclusion of the feasbility and preliminary design stage.

Data Acquisition and Survey of Resources. Local social, economic, and physical data are required to assure optimal design. However, physical data tend to dominate the engineering design. There are two basic types of physical data—fixed and varying. Fixed or static data include soil characteristics, topography, geology, and so forth. Varying characteristics include climatic parameters, weather, stream flow, groundwater, and even factors such as land use. If these parameters are not available at a given site, they must be estimated from nearby sites, from resource maps, from regional historical data, or generated using stochastic or simulation techniques.

Feasibility and Preliminary Design. During this stage, a system framework is developed that identifies the most probable water source, conveyance and distribution systems, and the approximate location and size of the command area. The framework is based on analysis of macro-level data and may be subject to modest change. Preliminary design should ideally include consideration of local human and material resources and the preferences of the local people. Evaluations are made of the water supply, the water requirements of the crops to be grown, the extent of possible irrigation, and the most appropriate technologies for water use.

At the end of this stage, the decision makers have a relatively well-defined concept of the system.

Detailed Component Design. Irrigation system components include the headworks, pumps, canals, canal structures (e.g., turnouts, check dams, siphons, etc.), and on-farm facilities (e.g., bunds, terraces, field drains, etc.). Component design determines the capacity, location, strength, and specific type of individual elements of the total system. Engineering design standards generally relate to appropriate component design and require site-specific information. Ideally, the level of detail in the design should reflect the quality and quantity of the data available. Based on a designer's engineering skills and the data available, specifications and blueprints of the system components are made. These blueprints, together with a schedule of construction materials and procedures and a plan for system operation, make up the master plan for the system.

Project Implementation. From an engineering standpoint, implementation normally includes the mobilization of the group responsible for construction, the collection and stockpiling of materials, and actual physical construction of the works. Management and detailed scheduling of construction activities, quality control, materials procurement, and financing are important tasks within this phase. Government and contractors generally consider the output to be the completed system. Land acquisition, resettlement of the project area (if necessary), and development of supporting physical and organizational infrastructure should also parallel this activity. Moreover, from an operational standpoint, changes or mistakes in the original design or poor construction may also limit the system's potential operation.

Operation and Maintenance. In order to meet the objective of sustained agricultural production, adequate provision must be made for planned operation and maintenance activities. Sufficient supplies of resources (financial, managerial, labor, and materials) are necessary. In the absence of these resources, system performance will decline. Unfortunately, it is only after construction is complete that the O&M plan can be tested to see if it is effective.

Evaluation and Rehabilitation. This stage serves as a feedback mechanism in the cycle of project development. The evaluation of the existing system and a determination that rehabilitation or retrofitting is required would essentially correspond to the identification stage in new system planning. Thus, the reentry point to the cycle would be at the start of the "data acquisition and survey of resources" phase (Figure 2). The importance of collecting and using the information developed from experience following initial project implementation cannot be overemphasized.

Traditional or Evolutionary Design Process

The evolutionary approach to irrigation development depends on local experience to provide the necessary information to improve, expand, or intensify a system. Locally-managed, small-scale systems that are highly efficient and productive are often quite old. Such systems perform well because they have the flexibility to adjust to changing needs; that is, project design and implementation are ongoing processes.

The fact that the evolutionary approach to development is not based on long-term planning makes it difficult to integrate this approach into government development plans. Also, considering how governments might infuse technical assistance into the evolutionary development approach, we consider how the conventional approach might be made more effective for government small-scale irrigation design by incorporating some lessons learned from locally managed, small-scale systems.

Goverment Small-Scale Design: Revising The Conventional Approach

For convenience we will use the seven stages previously outlined as a framework within which to discuss how the process might be altered to produce a procedure more appropriate for small-scale design. As mentioned earlier, some of the problems we perceive in the conventional design approach lie in the fact that implementation procedures are derived from experiences with large-scale systems. We also discuss the question of how to retain the positive characteristics (e.g., efficiency, production, sustainability, and maintenance) of traditional systems.

System Identification. One of the main reasons that many traditional systems are sustainable is that they are constructed and operated in response to felt needs of local people. At present, however, government and/or donor agency requirements and constraints often determine the procedure for selecting an irrigation system for development. An alternative to selecting sites based on often extremely crude and almost exclusively physical criteria would be to solicit requests from local communities. If communities really want an irrigation system, they can be expected to initiate the request if they are made aware of the assistance program. If farmers do not ask that their area be considered for irrigation development, then it is likely that they can see no benefit for their community.

A second important reason to have communities identify their own systems for development is that implementing agencies may be unaware of each community's individual needs if a large number of small systems are to be built or renovated each year. For example, the USAID Hill Area Development Project in Himachal Pradesh, India has a target of construction or rehabilitation of over 1,000 small-scale systems; the USAID minor irrigation projects in Madhya Pradesh and Maharashtra, India have goals of constructing between 50 and 100 systems in each state (USAID, 1983, 1984a, 1984b). Without the voluntary assistance of local people, system identification may be arbitrary. On the other hand, local requests not only provide evidence of a perceived need but also an important link to local experiential information, the only data source that is likely to be available.

Experience in the Philippines suggests the importance of identifying small-scale schemes that are wanted by the local people, even if extra time is needed to assure a clear understanding of agency and local expectations. In the Philippines, the initial stages of system planning were reportedly very slow, with many meetings required. Once construction was started, however, development proceeded much more rapidly with full farmer support, and, in the end, the engineer's tasks were easier. The total time required to complete the project was reportedly no longer than the conventional approach, and, in addition, farmers were better prepared to undertake system management responsibilities (Bagadion et al., 1980).

System identification undoubtedly still needs greater attention. One important step should be to encourage local participation in providing site-specific information for system identification. The design of a suitable rapid rural appraisal technique, as suggested by Pradhan et al. (1983) and Bagadion et al. (1980), could provide a funding institution with a social and technical profile of the proposed system within a relatively short timeframe.

Data Requirements and Acquisition. That the output from an engineering analysis is no better than the data input is a well-known axiom. However, intensive engineering analysis techniques are still used with poor quality data, which give the misleading impression that the analysis is as accurate as it is precise. In India, Sri Lanka, and the Philippines, canal design flows are typically calculated to a level of precision that cannot even be measured in practice. Rotational water deliveries are designed to the minute. This level of precision is not justified based on the available data for analysis in many developing countries. Even experiences with large-scale development projects have repeatedly demonstrated a lack of site-specific data, including material relating to hydrologic conditions, topography, soils, and a variety of other critical agronomic, climatic, and social data. For small-scale projects, extensive data collection by conventional methods is almost impossible because it would require much more time and money for individual systems then are typically available for such activities.

The type, detail, and accuracy of project data needed are usually dictated by the predetermined design methods to be used. Algorithms used in conventional design procedures are usually extremely data-intensive, and the values of many variables must be determined or assumed before a solution can be derived. Often these procedures are also very sensitive to the data that is not available (Murphy's Law). Assumed or estimated values can easily lead to erroneous results, particularly if the estimated values are drawn from empirical relationships derived for a different region of the world. For example, the use of the US Soil Conservation "Curve Numbers" for determining rainfall runoff hydrographs from agriculture lands in the U.S. is not necessarily applicable to parts of the humid tropics where rainfall patterns and agricultural practices are quite different. An alternative approach might be to do preliminary assessment of the data availability for a project area and then, based on the type and quality of data available, select the design method to be used. The most accurate and realistic designs will result from the most rigorous analysis techniques that can be properly used with the data available. The quality and type of data usually available for small-scale irrigation may dictate a fairly low level of rigor in the design techniques.

Experience indicates that farmers can provide a wealth of local, site-specific information if we can learn how to use it in conventional design. They are usually intimately familiar with the rights of access to and characteristics of local water sources, sizes of landholdings and tenure patterns, subtle differences in land elevations, and the effects of climatic variations on the crops they grow; in fact, their very cropping patterns frequently reflect a conscious adaption to these environmental conditions. Often local farmers have developed an accepted norm for equity in water allocation or right to water utilization (Martin and Yoder, 1983; Duewel, 1982). Moris et al. (1984) note that farmers in southern Niger have a keen understanding of the water balance and the ability to make quite accurate assessments of how much water their crops need in an arid environment with sparse and unpredictable rainfall. Discussing large-scale systems, Levine and Hart (1981) state that "local knowledge can be an important source of detailed information necessary for the appropriate design, rehabilitation, and operation of minor distribution and terminal works."

Unfortunately, procedures for translating local information and knowledge into conventional engineering design parameters are not well developed. Farmers and engineers can probably communicate better on the appropriateness of the end product of a component design (e.g., height of a dam, size of a command area) than on specific design parameters (e.g., soil infiltration rate, crop evapotranspiration). In any case, we believe it is important for engineers to learn as much as possible from the farmers and, to do this, the engineer and farmer must develop a two-way dialogue, although this is not an easy process. The chances are high that the engineer will not be a native of the project area and, therefore, will need time to become acquainted with the physical environment and to develop an understanding of local resources, culture, and institutions. Farmers will be confronted with a "foreigner" in their midst and will need the chance to adjust to the newcomer (this situation is not confined to developing nations). Once a degree of trust and understanding has been built up between the two parties, a two-way flow of information is generally possible.

Feasibility and Preliminary Design. The output from this stage of conventional development is an irrigation system framework. The stages following feasibility are directed toward refining the design of components and creating greater specificity in the design. Major conceptual changes are typically not made following the preliminary design. We believe that conventional engineering analysis dominates this stage of development, which reduces the opportunities for more imaginative or appropriate designs.

The term "system architecture" might help make an important conceptual distinction between the imaginative process of piecing together the various parts of a system by a multidisciplinary group including local farmers, and the relatively straightforward, technical task of engineering feasibility studies. Furthermore, it emphasizes the functional characteristics of the system in which management and operation must be primary considerations.

Farmers should be key participants in developing the system architecture. It is argued that by encouraging active participation by the local community in the decision making process, projects have a higher change of success (Uphoff, 1984). Experiences with participatory programs in the Philippines and Thailand (Bagadion et al., 1980; Mayson, 1984) indicate that farmers are highly rational about what facilities they feel are necessary, particularly when faced with the requirement to repay a loan, rather than receive a grant.

Also, since farmers will generally be responsible for operating and maintaining small-scale systems, even government-designed systems, they should be intimately involved in developing the framework for operation and maintenance. Not only would this help in clearly defining the required operational characteristics, but would also allow other factors such as water rights to be considered in the management plan.

Where systems fail to perform as intended, it is usually because of poor or no system architecture rather than poor technical design. The quality control of component design (the stage following feasibility) may be quite good in terms of meeting accepted design standards but this is somewhat immaterial if, based on nontechnical factors, the chosen component is inappropriate. System architecture should be based on social, cultural, and economic as well as technical considerations. Feasibility studies to determine if systems meet final selection critieria should be based on a system architecture not on preliminary engineering design.

For example, Levine (1979b) suggests that design engineers rarely consider the full range of development options, but become "locked into" a design that is dominated by technical considerations in the preliminary design phase. He notes (Levine, 1979b:14-15)

> . . . the system design process normally has a sequence of decision about the basic water supply (run-of-the-river, storage groundwater) made very early, with decisions about general operating rules made at a later stage and with decisions about specific organization, extent of the conveyance systems, and structural details made still later in the process. There is some iteration in this process, with information developed in later stages being used to modify the decisions of the earlier stage, but the modifications usually relate to details rather than to the basic approach, and they tend to reflect adherances to the original ideas rather than open consideration of the developing alternatives and choices. As a result the early decisions are

> crucial and tend to reflect a bias toward or at least an emphasis on the physical infrastructure. . . . When the disciplinary makeup of design teams—with primary, if not complete emphasis on technical skills (engineering, soils, agronomy)—is recognized, the emphasis on the 'hardware' elements is inevitable.

Also, there is a common preoccupation of designers with the concept of "water-use efficiency." Levine (1979b) suggests that a designer should anticipate only modest efficiencies during the early stages of project development. These tend to improve with experience and management capabilities and vary according to the seasonal or local scarcity of water. Svendsen (1983) suggests the use of the relative water supply (RWS) variable, which is essentially the inverse of the efficiency.[1] He notes that (Svendsen, 1983:5)

> The importance of this transformation is that it changes the nature of the efficiency/RWS variable from dependence to independence and tends to change the way we think about the relationship between farmers' efforts and effective utilization of water. . . .
>
> To system management personnel, improved system efficiency may be an unquestioned good to be pursued relentlessly. To the farmer, on the other hand, improved water use efficiency at the tertiary level probably means less water, more work on his part to manage the water he does get, and undiminished irrigation service bills. We should not be surprised if he fails to share the engineer's enthusiasm for greater efficiency. In most cases, the farmer's preference would probably be with reduced efficiency and the luxury of having the additional water that would thus come his way.

In small-scale systems, in which the farmers will presumably assume a large portion of the responsibility for management, the determination of an initial

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[1] Svendsen defines RWS as follows:

$$\frac{PPT + Q}{ET + SP} = RWS = \frac{1}{EFF}$$

where PPT = precipitation, Q = irrigation deliveries, ET = evapotranspiration, SP = seepage and percolation, end EFF = efficiency. A RWS value of 1 means that water supply is exactly equal to plant and soil needs; a RWS greater than 1 indicates that water supply is more than adequate to meet plant and soil needs.

command area on the basis of a high RWS (a high ratio of water supply to basic crop and soil demand) would therefore seem more appropriate than attempting to achieve a high "water-use" efficiency from the start. As experience with irrigation and with the system increases, more productive use of water should occur, if indeed water is a limiting factor.

What is needed, therefore, is a considerable degree of program flexibility, which in turn will have a direct influence on the architectural development of the system. On the one hand, the implementing agency needs to periodically review the progress of each project and to be in a position to revise procedures and budgets to remove programmatic constraints in order to allow a more responsive system growth. On the other hand, local participation in the decision-making process and eventual local ownership of the system need to be built into the program to encourage maximum input of local knowledge and resources. The optimal approach will differ considerably from one setting to another, and should be allowed to develop as a result of program experience.

Component Design. There is considerable engineering and traditional experience throughout the world in the design and detail of irrigation structures. One of the major difficulties conventionally trained designers appear to have, however, is an inability to make allowances for the practical operation of the completed system in unfamiliar settings. This, in many cases, is a result of the designer's lack of understanding of conditions at the field level. For example, a common criticism of large irrigation systems is that a set of component designs found to operate successfully in one area of the world (frequently a developed area) is reproduced without due modification for different management practices in another (often a developing area). While the hydraulic principles on which the design is based may be similar, construction methods, materials, operating conditions, environmental exposure, and maintenance practices are often entirely different. Similar problems exist when structures designed as components to be used within a large system are incorporated into small-scale systems without modification.

The term component design may be interpreted in various ways. For present purposes, it is assumed that component refers to all works or structures created to capture, control, conduct, and deliver water to the plant. This, for a surface water system, would include the headworks, storage facilities, canals, control structures, measuring structures, and the on-farm water utilization system, all of which, together with the source, must be taken into consideration in the component design process. Groundwater systems would consist of a similar range of components, with the water-lifting device (pump) taking the place of the headworks.

As noted earlier, there is commonly a shortage of quantitative design data for small-scale systems required for use in conventional engineering design algorithms, and, in many instances, these algorithms may be inappropriate under the given circumstances. The challenge facing the engineer is to utilize the locally available data to create a functional design. Many of the sophisticated techniques now available must be replaced by a return to basic engineering analysis, and a more innovative and imaginative approach to design must be employed. Higher "factors of safety" against failure than typically used for engineering design should be considered to account for problems of quality control, environmental exposure, and uncertainties in basic design criteria (e.g., flood flows). However, such a "conservative" design approach sacrifices engineering "efficiency" or perfection, and structures may be initially more costly and require more materials. These trade-offs must be considered in the light of other design and operational criteria.

An alternative approach to using high factors of safety might be to design a portion of the structure in such a way that it fails before the rest. An example of such an approach would be a dam with a "fuse-plug" spillway. If a large flood occurs, then the spillway section of the dam washes out in a controlled way, leaving the main section intact. The "fuse-plug" can later be reconstructed with locally available fill material. In some cases, permanent headworks for small systems will be too expensive and design of a temporary structure will be needed.

In most of the industrial nations, comprehensive design standards and codes are used in the preparation of engineering designs. In many of the developing nations, such standards may not exist, or may have been borrowed lock, stock, and barrel from a developed neighbor (this creates problems similar to those encountered when designs are imported from another geographical region). In other situations, national standards or guidelines may be excessively specific, failing to account for local differences in environment. For example, in Sri Lanka, the Irrigation Department's Technical Notes state that the actual water duty (the area that can be irrigated using a unit flow of water) is 30 acres/cusec (3.1 litres/sec/ha) at the field channel level for rice cultivation. This makes no allowance for local variability between and within schemes, and the lack of discharge measurements makes it difficult for irrigation engineers to assess changes in demand that result from local variations in soil and requirements of different crops (Murray-Rust, 1983: 31).

The outcome of this situation is that many project design offices draw on a set of standards and component designs that have previously been widely used or have been found to work reasonably well in that country. This approach has several advantages from the designer's standpoint; the need to rethink the structure is reduced, designs may be prepared more rapidly, and the resulting design has the appearance and acceptability of previous designs. The disadvantages of this approach are also important to consider. In many instances, the designer will simply alter, enlarge, or make minor changes to a tracing of an original drawing, often without recalculation of the design principles on which the original design is based. The design itself may be an "imported" design of the type already mentioned and may not be adapted to local conditions. In many instances, erroneous assumptions made in the design of the initial structure will not be corrected in the new structure. Designs that emerge through this process without real evaluation of their operational function or their ease of maintenance become "clones" of earlier mistakes. The development of more flexible, appropriate local design standards and codes would undoubtedly go part of the way toward solving the problem of component structural design.

Considering the lack of design data discussed earlier, the process of component design typically employed by agency engineers and consultants does not fit small-scale irrigation projects well. A more flexible approach to the design of small-scale structures may be one in which the engineer prepares a "field design." The engineer draws on local input and information, considers several alternatives, solicits immediate feedback, and sketches out a design in the field. The use of a catalog of structures might assist him in discussing the various alternatives with the farmers and in detailing the structures chosen. Such a catalog would contain a three-dimensional sketch or photograph of the structure, specifications and detailed drawings of the structure, and the conditions under which the structure could be used (Mayson, 1984). The catalog must be based on local experiences, standards and practices, rather than relate to conditions prevailing in other countries. Many agencies and organizations have attempted to compile such documents often intentionally simplified. However, problems such as poor distribution, poor targeting of intended users, and lack of active support by the professional engineering circles (perhaps as a result of their simplified approach) restrict their use and circulation.

Implementation. Implementation was earlier described as the process of organizing, collecting and stockpiling materials, of mobilizing labor, and the physical construction of the works. These activities call for a high degree of organizational capability and rely, to a large extent, on group cooperation for timely progress.

Small-scale irrigation system construction is generally not big enough to interest large, national, or international construction firms, so it is often undertaken by the local sector. Local contractors frequently lack experience in the construction of hydraulic structures. In Bangladesh, when contracts were awarded by open competition for small-scale government works on a site-by-site basis, the larger, more experienced contractors were rarely attracted. Instead, smaller, less experienced, local contractors were chosen, although they were often poorly qualified in a technical sense, lacking sufficient management and financial resources (Wensley, 1984). Training programs may be needed to improve the skills of local contractors. These could be built into government-assisted, small-scale irrigation projects.

Local contractors may intentionally be used in an effort to spread benefits. Benefits can also be spread by giving the farmers or local organization control over the funds, making local contractors answerable to the eventual system users, rather than to an impersonal, centralized government agency. This has been achieved with some degree of success in northeast Thailand (Mayson, 1984).

Local contractural procedures may often be considered unethical by "Western" standards. Tales abound and some evidence exists regarding informal payments made to officials in the process of awarding government contracts (see Wade, 1982). Consequently, there may be considerable opposition to removing financial, and therefore effective project control from the government agency in some countries. Initiating a system of local accountability for funds could provide an alternative to effectively ignoring such informal payments. Working through private voluntary organizations (PVOs) may provide another alternative.

Planned construction time-frames are often unrealistically short. Construction seasons vary with the location and climate. In a large part of the humid tropics where small-scale projects are undertaken, seasons are typically marked by a cycle of rain followed by dry weather. Access and construction activities are often restricted by the rainy season and subsequent floods. Construction activities frequently compete with agricultural activities for available labor, further shortening the construction season.

Construction materials cause further difficulties. In many cases, concrete and reinforcing steel, together with manufactured components (gates, etc.), form the basis of the majority of conventional designs. Shortages of any of these items during the construction phase can cause considerable delays. Lack of experience in working with specialized construction techniques often associated with hydraulic structures (for example, laying concrete under water, pouring massive amounts of concrete at one time, and special construction joints) can lead to considerable difficulties. Quality control, such as maintaining the correct portions of ingredients in a concrete mix (when the constituents are relatively valuable on the local black market), or preventing deterioration of materials due to climatic influences, are very serious limitations in many projects. In an effort to improve quality control of construction, USAID is proposing to fund over twenty quality control workshops as part of its minor irrigation projects in Madhya Pradesh and Maharashtra, India (USAID/India, 1984b).

The use of local materials for construction will often bypass problems of supply and lack of local experience with outside materials. As discussed above, it is a challenge for the engineer to adapt the design process to make use of local materials. From a funding point of view, donors and government agencies may be hesitant to provide assistance when materials of a more temporary or unconventional nature are used. An economic analysis of the costs and benefits associated with local materials, coupled with the facility of construction may, in many cases, support their utilization in small-scale irrigation development.

From another perspective, the use of local materials and structures of a temporary nature may require that the farmers expend a continual effort in the maintenance or reconstruction of such works. Permanent structures, particularly for the headworks required to capture the water, are generally found to be preferable but, in some cases, the cost per unit area irrigated of the headworks is excessive. Involvement of farmers in the decision making process will enable the tradeoffs between component design alternatives and technologies to be evaluated.

Pressure to complete projects, particularly the requirement that systems be completed to be eligible for reimbursement, dictates that many components must be built before the system delivering water to them has been tested. A good example of such a structure is the field turnout. In many instances, these are positioned by the designer in the master plan on the basis of a topographic survey. Survey resolution may be 0.3 meters, and the accuracy with which the elevation of the given point can be determined is about ± 0.3 meters (by interpolation between contours). Serious difficulties in water delivery may result when the level in the canal and the field differ by a few centimeters (see Moya and Early, 1980). In practice, many engineers recognize the need to locate such structures in the field, and vandalized structures (USGAO, 1983) are evidence of farmers' frustrations with poorly positioned structures. A more effective approach may be to allow farmers to construct temporary turnouts initially, and to make them permanent at a later stage.

Operation and Maintenance. Throughout the process of design, operation and maintenance or, more generally, management must be a primary focus for the designer. Both the system architecture and individual components have management possibilities and limitations built into them. Furthermore, operation of the system occurs within an organizational framework of water users and local or agency system managers. This organization generally functions to allocate and distribute water, mobilize resources, maintain the system, and manage conflicts (Chambers, 1980). System design must address each of these issues.

In the area of water allocation, there must be an understanding of local rights of access to water, both legal and customary, and the way in which they are enforced. In designing a new system, a knowledge of these rights will generally determine the system architecture and where the water will flow. In existing systems, there may be prior rights of access by the present group of irrigators. An awareness of these rights will allow the designer to provide an apporpriate set of complementary physical components. Failure to recognize and incorporate water rights and access into system design will result in severe conflicts or systems' failures.

Martin and Yoder (1983) document two distinctly different systems of allocation in use in hill irrigation systems in Nepal; one in which the farmers allocate water on the basis of land area irrigated and the other on the basis of ownership of water shares. In the latter system, members of the community that developed the water delivery system divide ownership of the water shares among themselves on the basis of resource input. The shares are not tied to a particular parcel of land, but may be sold, rented, or subdivided. This system of allocation provides greater incentives for efficient water use and promotes greater flexibility in system expansion. Similar principles of share distribution are documented in Spain and the USA (Maass and Anderson, 1978).

Various methods of water distribution and delivery within the system are possible: rotation, continuous flow, or a combination of these at various levels within the system. The farmers' perception of equity plays an important role in the determination of which system is used (Levine and Coward, 1985), as do management capabilities and the availability of water. In many systems, irrigators at the head-end of the system are generally more fortunate than tail-enders in terms of water availability. This situation is often more complex due to various soil types and cropping patterns within a command area. These imbalances in supply must be recognized and taken into account in short- and long-term management plans.

Increasing awareness of the importance of social interactions between water users and in their dealings with government agencies points to the need for a multidisciplinary approach to system understanding. As Lynch (1985) argues, a knowledge of the social environment within which the system functions is paramount in small-scale system development. This is particularly important if farmers are expected to operate and manage the system. The level of their involvement in the initial development phases will have a direct effect on later system management.

Several rapid rural appraisal techniques have been developed to assist the field engineer or agricultural technician in developing an understanding of local social conditions (Chambers, 1983). The importance of social science input into the design process cannot be overstressed, although it is often difficult to identify those persons most qualified to assist in the design process. In Sri Lanka, the use of specially trained institutional organizers has met with considerable success in developing the capacity of local water-user associations in large, government-managed, irrigation systems (Uphoff, 1982). Similar techniques have been employed in the Philippines and could be extended to new small-scale irrigation systems elsewhere.

Measurement of flow is generally considered to be an important component of system operations because of the limited availability of water in many systems. Methods used to determine the quantity of flow range from approximate, relative measures to more exact quantitative measures. It is common to hear of measurement structures in modern systems being willfully damaged by farmers (USGAO, 1983), possibly because farmers perceive them as restricting the flow. Timed rotations or proportioning of flows are commonplace, but it is unusual for operators to consider absolute quantities of water except in large systems. On the other hand, farmers are very aware of relative supply levels in the canals delivering water to their fields. Their concern is not only quantification of flow, but also the reliability of supply. For this reason, the provision of sophisticated measurement structures might be considered applicable only in a system that has developed a high degree of management capability and experience. A concentration of initial investment in structures that improve control and the reliability of supply (such as canal linings) would therefore seem most appropriate.

In many traditional or indigenous irrigation systems, the users have developed mutually acceptable operating principles, often without sophisticated measurement structures (see, for example, Martin and Yoder, 1983). On the other hand, operating procedures in conventionally designed irrigation systems are often poorly conceived or defined. Often, the operators receive little instruction in system operation, and are inadequately trained and equipped to undertake this role. Budgets for ongoing operation and maintenance of government-owned systems are typically lacking, resulting in poor performance compared to many traditional systems.

As argued earlier, farmer responsibility for system operation and maintenance must take place within an environment of ownership (Coward, 1983a). In the absence of local ownership, the collection of water fees, the mobilization of labor, and the provision of materials for maintenance and rehabilitation rests largely with the government agency concerned, often resulting in severe system deterioration when resources are not provided (USGAO, 1983). It would seem in the agency's best financial and managerial interests, therefore, to invest in small-scale systems in such a way that farmers assume or retain ownership on completion of development. This is not to say, however, that the agency should lose interest in the system after handover; rather it should provide follow-up service to improve management and organizational capabilities. Assistance programs that encourage a large input of local resources into the development process in addition to external resources are also likely to have a positive effect in fostering farmer responsibility for the completed system (Mayson, 1984).

Evaluation and Rehabilitation. Rehabilitation, particularly of large systems, is gaining increasing attention (USGAO, 1983; Steinberg et al., 1983). The failure of large investments in system hardware to produce anticipated benefits and, in many instances, the rapid deterioration of these systems raises important questions about rehabilitation. As noted earlier, system design must take management practices and desires of the eventual water users into account. If this is not done, it is logical to assume that the resulting system will fail to serve their needs and quickly fall into disrepair. In system rehabilitation, a thorough revision of the original design concepts and assumptions needs to be undertaken in the light of existing operating conditions. Very often, rehabilitation is interpreted as reconstruction of the original structures. This invites a similar system deterioration process to occur. Rehabilitation must therefore be undertaken with the same degree of study and input of engineering design (or redesign) that is used in new works. As with a new system, a similar process of development must take place, recognizing the preexisting system components and local organizational structure (Coward, 1983b).

When system performance is evaluated, reference is often made to original design criteria. In practice, original design criteria may be guesswork, but these are commonly used as a basis for system evaluation. For example, in Bangladesh, planners assume that a tubewell designed to supply 1 cusec of water will irrigate 50 acres, but this may not be the case in all areas due to site-specific conditions. However, any system that does not meet this criterion is considered to operate poorly. There is no justification for this assumption and no attempt to correct it. When distinctions are not made between design and evaluation criteria, poor performance is likely to be reported. Moreover, Bagadion et al. (1980) note that there must also be a shift in evaluation from simply completing a construction schedule to an emphasis on achieving farmer satisfaction with the completed system.

It is useful to consider the concept of "retrofitting" in relation to rehabilitation. If system growth can be described as evolutionary or incremental, making better approximations to the system architecture with each improvement, then the idea of returning to a functional system to improve and "retrofit" components is an important distinction from rehabilitation, where system "deterioration" is assumed. A diagnostic analysis, such as the procedures developed by Colorado State University (1983), might be used to identify constraints in existing system performance to provide a basis for future improvements.

Government Small-Scale Design: Evolutionary Approach

In this section we examine opportunities for government and other external technical assistance to systems that follow the traditional "bottom-up" approach to development. A fundamental difference between the conventional and evolutionary approaches to small-scale irrigation development is in who makes the important decisions about the framework of the system. In the conventional approach, government professionals, often specialists in a particular discipline, predominantly engineering, decide on a preliminary design before any detailed design or construction takes place. Under the evolutionary approach, the farmers decide what will initially be done in the first phase of development as well as in subsequent years as changes are made in the system. Our experience, as well as that reported by others, indicates that if government personnel are the primary decision makers as to what a system is to be, the government will be seen by the farmers as having control over and operational responsibility for the system. Evolutionary schemes are built in response to locally felt needs and remain under farmer ownership and control.

The programs of the United States Soil Conservation Service (SCS) and Agricultural Stabilization Conservation Service (ASCS) are examples of government technical and financial assistance given to private farmers where farmers are the decision makers. In the case of the US programs, farmers choose among alternatives that meet the government agency standards and criteria. Typically, technical assistance is arranged through SCS-farmer interactions, resulting in a compromise that maximizes both the SCS objectives (e.g., usually resource conservation) and the farmers' objectives (e.g., usually economic maximization). The final decisions as to what is to be done in the field through an SCS program are made by the farmer.

One of the primary advantages of evolutionary development appears to be a high economic efficiency that results because major investment in inputs, including new technology, are not made until they can be effectively used. Compared to conventional development, the inputs are low in the first stages of evolutionary development. The initial technical efficiency of a locally managed, small-scale system may also be quite low. However, as local skills improve and confidence in the system increases, the farmer perceives less risk and consequently makes greater incremental investments in the systems. There is a balance between the investments made in the system and the output that can be realistically expected (see Figure 1). The conventional government approach, on the other hand, is driven by criteria, particularly economic criteria, that encourage a large initial capital investment with the assumption that maximum output potential will rapidly occur.

Experience suggests that designers are overly optimistic about the initial levels of (1) farmer and system operator irrigation management skills, (2) farmers' willingness and ability to invest in inputs and take responsibility for tertiary development, and (3) the ability of local farm services (e.g., markets, credit programs) to adjust to the change in farming systems brought about by irrigation. Increased attention to appropriate technical training at all levels of irrigation operation and management could help government systems overcome these limitations, allowing the systems to operate as designed and reach their production potential more quickly. Very likely, technical training, which could be provided through government assistance, would also accelerate the speed at which evolutionary development takes place. Experience has also shown that where new and appropriate technologies are introduced in demonstration projects, they are adopted relatively rapidly by neighboring farmers. In the late 1960s, Catholic Relief Services (CRS) initiated a well development project in tribal areas of Bihar, India that had no previous irrigation experience. Informal observations by the CRS staff administering the project suggested that it took four to five years for the first farmers with wells to use irrigation effectively. However, in the same area, wells currently constructed are effectively used in the first year (Xavier Institut, 1984; de Brouwer, 1985).

One reason given for USAID's increasing interest in small irrigation systems is that investment in this sector "reduces the gestation period (as compared to large systems) between project initiation and system operation" (USAID, 1984b). In USAID/India irrigation projects, the physical infrastructures of small-scale systems are expected to be constructed in less than one year. These projects have technical training programs integrated into them to help operators and farmers to manage the systems. However, the length of time it will take for the software component of the systems to fully develop, even with training assistance, will certainly be much more than a year.

The conventional approach to design given in Figure 2 shows the output of stage five as a "completed system." In reality, it is at this point that development really begins. Conventional developers typically consider a system where funds have been spent and physical infrastructure built to be "completed" (in some cases operator training has also been included). A system is "completed" from the evolutionary point of view when the environments (physical, economic, and social) that have been changed by introducing irrigation have again reached stable balances. If governments are to assist in small-scale irrigation development following this approach, they must give assistance carefully and at a modest pace so that the local environments have a reasonable chance of adjusting to the imposed changes. Many of the positive attributes of the small-scale, evolutionary approach such as learning-by-doing, reliance on existing farmer knowledge, mobilization of local skills, low per acre cost (due to low level of initial inputs), and the like will be negated if the development pace is too rapid or if technology is introduced that is too foreign to the water users. Outside development can probably be used to encourage local development to proceed at a faster pace and to encourage the use of more efficient technology. But too much or forced government assistance will kill the indigenous motivation that drives the traditional approach.

The level and type of external technical assistance that can be given while maintaining a traditional pattern of development depends on many factors. Complete system designs, sometimes referred to as turnkey designs, rarely ever operate as planned because they are insensitive to specific local conditions. The turnkey system usually represents too much technical assistance, except in the unusual situation where a large geographic region is homogenous (socially, economically, and physically). On the other hand, standardization in design of some system components can be successfully done for small-scale irrigation. A component such as the tertiary canals might have a standardized method of lining that is applicable over a fairly broad area, but the location of the tertiary canals requires detailed site-specific data. In southern Bihar, India, an irrigation project administered by CRS using assistance from USAID Food for Work Program was observed. In this project, a standardized design for dug wells was adopted and has been successfully used for some 25,000 wells in the Ranchi District. The design is based on readily available and abundant local resources; rock and labor in the dry season. The water lifting, distribution, and on-field water utilization techniques are not standardized and differ between farms depending on particular cropping systems and resources available to the farmers (Xavier Institut, 1984).

In this same project, CRS has built about 800 small surface irrigation systems with command areas less than 40 hectares each. These surface systems frequently failed to perform up to expectations because, in the opinion of a local CRS director, the designs for the dams were not based on site-specific conditions but rather on a standardized design (de Brouwer, 1985). The CRS respresentatives at Ranchi in Bihar told us that access to qualified engineering assistance in headwork design was a major need in their small surface irrigation systems.

The above example also illustrates that external agencies are improtant mechanisms for technology transfer. In the case of the CRS project in Bihar, the well technology was new to the area, but it was not a "modern" technology. The same dug well technology used in Bihar has been used in other parts of India and the world for hundreds of years. The locally-known technology options for any single, small, traditionally developed irrigation system are usually quite limited. Therefore the opportunity for externally assisted technology transfer is quite large and should include proven technologies whether modern or not. In fact, in many cases, the transfer of a technology that has been successful in one developing area to another might be more appropriate than the transfer of a modern technology (usually designed for a developed country) to a developing country.

In countries with considerable experience in traditional small-scale irrigation, a qualified institution could be identified to collect and analyze data from small-scale experience and then feed this information back to aid in new designs. This center could not only give design guidance but also provide training for field and agency personnel and support to universities with interest in small-scale irrigation. Such a center should probably not be limited to technical issues only.

Finally, even if small-scale irrigation design and implementation are done following the conventional government approach, ultimate operation and development of the system will be decided upon by the farmers. Even if the master plan assumes otherwise, the system may follow evolutionary patterns similar to traditional development. Levine (1982) cites examples of this pattern in Latin America and Thailand. Development of a conventional master plan, however, may be a good approach to design as long as the engineer-dominated decisions are restricted to the headworks and primary canals, leaving flexibility for farmer decisions based on experience for development at the lower end of the system. Experience in the Philippines would tend to support this approach (Bagadion et al., 1980). The master plan developed by the government professionals could provide water users with valuable insights as to development potential that they themselves are not able to predict. Such a master plan could guide the farmers and give greater assurance of an efficient development. However, the master plan must not be seen as a blueprint to be rigorously followed, but rather a plan that will be continuously modified based on new information constantly being generated as the system is operated.

Conclusions and Opportunities for Further Research

The optimal approach for governments to provide technical assistance to small-scale irrigation development will vary from country to country and even case to case within a country. Probably a blend of what we have defined as the conventional and evolutionary approaches would be appropriate in many situations. If government intervention in small-scale irrigation design follows the same pattern as large-scale, the resulting systems will almost certainly perform very poorly. Changes in the conventional government approach to irrigation design must be made if small-scale irrigation is to maintain the advantages that result from local control of the systems.

Throughout the paper we alluded to many areas of potential research in the design of small-scale systems, which we summarize below.

Conventional Approach

1) We believe that local participation in project identification and in subsequent design and construction activities, is an important determinant of project success. However, there must also be an important component of overall planning and allocation of resources among project beneficiaries. How these two activities can be coordinated and implemented to achieve a set of stated objectives has yet to be addressed.

2) To overcome the lack of detailed technical information on small-scale irrigation systems, we suggested that local knowledge can be incorporated into the design process. Research is needed to develop systematic methods to translate this knowledge into quantifiable design parameters and to take account of the uneven quality of such data.

3) Research is needed to develop a flexible approach to designing system "architecture" and to be able to make adjustments to the system through the design, construction, and subsequent development phases in response to new and improved information. Emphasis must be placed on the multidisciplinary nature of the task, recognizing in particular the importance of existing government and local infrastructure and local agricultural practices.

4) The design of individual structures needs to be improved in many ways. Designs must recognize the management opportunities created and limitations imposed by the choice of structure and also make best use of local resources (e.g., construction skills and materials and limited site-specific data). Present analysis techniques are inappropriate in many respects; new, innovative techniques need to be developed to accommodate local site and operating conditions.

5) The objectives underlying the design and operation of both systems and individual structures need to take account not only of technical factors, but also agronomic, social, and economic factors. For example, the technical goal of water-use efficiency should be weighed against less easily quantified goals of equity and productivity. Methods to evaluate and rank these objectives, particularly in small systems, need to be developed.

6) Many opportunities exist to improve the process of project construction. These include training of contractors, improving quality control measures, simplifying contractural and reimbursement procedures, etc. Also, the advantages and disadvantages of construction by the local sector (as opposed to large public works or other forms of labor mobilization) are location-specific. Research is therefore needed to identify the most effective process for small-scale construction in areas likely to be targeted for development assistance. Ideally, this research should be carried out before project plans are formulated.

Traditional, Evolutionary Approach

1) As noted, few experiences in government assistance to small-scale irrigation projects, particularly from an engineering perspective, have been documented. Review of past and current programs of technical assistance needs to be undertaken to provide programmatic guidelines for future government assistance to the local sector.

2) It is widely assumed that small-scale projects, by virtue of their size, are more quickly implemented and have the potential to realize the benefits of investment more quickly than large-scale projects. At present there is little data to support this assumption. How quickly these projects can be built and

how long it takes for farmers to develop the confidence and skills necessary to operate these systems should be studied.

3) In the paper, the possible adverse affects of government assistance to local systems were discussed. It was suggested that care should be taken to determine the level of involvement to avoid negating local initiative and motivation, and causing an imbalance of the local environment. The level of assistance that can be given to local systems to avoid these adverse affects needs to be studied.

4) External assistance for technology transfer and adaptation seems appropriate and potentially effective for improving systems developed following the local pattern. However the most appropriate technologies may not be those that are modern, but rather proven traditional technologies from other locations. A survey of existing appropriate technologies and how best they can be used in other regions is needed.

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