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IRRIGATION SCHEME WATER MANAGEMENT

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PREFACE

This study was conducted as part of the Water Management Synthesis II Project, a program funded and assisted by the United States Agency for International Development through the Consortium for International Development. Utah State University, Colorado State University and Cornell University serve as co-lead universities for the Project.

The key objective is to provide services in irrigated regions of the world for improving water management practices in the design and operation of existing and future irrigation projects and give guidance for USAID for selecting and implementing development options and investment strategies.

For more information about the Project and any of its services, contact the Water Management Synthesis II Project.

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IRRIGATION SCHEME WATER MANAGEMENT[1]

by Jack Keller[2,3]

The purpose of this paper is to present some useful conceptual/visual frameworks for thinking and communicating about the management of irrigation systems and the schemes they serve. Assuming the objective of irrigation development is to improve human well-being, addressing water management at the irrigation scheme level is thought provoking. It begs the following questions: what are irrigation schemes and their objectives; what is water management and the objectives of it; how can we best communicate and think about irrigation management within and between the discipline areas involved; and would using the word "system" instead of "scheme" make any difference?

I will give answers to these questions. The answers and the rest of the material which follow are an effort to articulate my thoughts on these matters as clearly as I can at the moment. What is in my mind, in turn, results from meditating on my field experiences, in view of the words from many professional colleagues. While I value their written literature dearly, my many stimulating discussions with professional friends have been even more valuable.

The remarks which follow are organized into three topical areas: the context of water management; an overview of irrigation systems and the schemes they serve; and requirements for managing large-scale irrigation systems. The organization of the material is original and unique, especially the overview section. However, the individual thoughts contained in this presentation have probably all been stated (orally or in writing) before. Therefore, I will neither attempt to justify nor credit all of the statements by citations, however, a list of a few pertinent references is attached.

WATER MANAGEMENT

Lowdermilk (10) defines irrigation water management as "the process by which water is manipulated (controlled) and used in the production of food and fiber...(It) is not water resources, dams, or reservoirs to capture water; nor codes, laws, or institutions to allocate water; nor farmers organizations; nor soils or cropping systems. It is, however, the way these skills and physical, biological, chemical, and social resources are utilized for improved food and fiber production."

Quoting from Lenton (9):

> "Improved irrigation performance depends on the management, not only of water, but of irrigation systems as a whole, including management of information and controls; of people (farmers and those who work in irrigation organizations); and of other inputs besides water. In essence, the management of these elements revolves around water and its control."

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[1]This paper represents the author's interpretation of some of the pertinent "lessons learned" between 1979 and the present, through USAID's Water Management Synthesis I and II Projects.

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"In addition to better water control, a set of objectives is necessary for management. There is no management without water control and objectives. Management refers to the operation of the system to meet the objectives. To check whether the objectives are met or not, the system performance must be monitored and evaluated and a feedback control mechanism devised to meet the project objectives."

Paraphrasing from Peterson (11) who poses and answers the following question: in view of all our advances in and knowledge of irrigation technology, why is it that irrigation systems and the schemes they serve fall so notoriously short in terms of what reasonably could be expected? Authorities generally now believe that the difficulty lies in the failure of irrigation schemes to be systematically operated. Water deliveries to fields do not match crop needs; and other production inputs such as seeds, pesticides, fertilizer, labor and technical knowhow are not available in a timely fashion. The farmers who are responsible for managing the crops are normally not involved in planning and managing the water and other input delivery systems. The various subsystems making up the scheme with its human parts requires multidisciplinary diagnosis, study, thought and action. The subsystems can only be studied in vivo, not on experiment stations or by controlled experiments on farms. Diagnosis requires an inductive or clinical approach rather than the deductive approach of the agricultural and physical sciences. These are the ideas one hears about the new approach called water management.

The term "irrigation system" is generally used too loosely. It is used to mean anything from a small-scale water supply and application system to an entire agricultural scheme served by a single large-scale or multiple small-scale water supply system. For clarification I will restrict my use of the term irrigation system to the capture, delivery, application and removal of water from agricultural land. I will use the term irrigation scheme to refer to the entire irrigated agricultural production system which an individual or group of irrigation systems serve plus the associated watershed, inputs and effects of the enterprise.

I will use the term irrigation scheme management to mean the management of the watershed and the irrigation systems as a whole, plus management of information and people, and of the necessary production, financial and institutional inputs; the term irrigation system performance as a measure of an irrigation system's success in achieving established objectives, often defined in terms of overall operational efficiency and meeting equitable water delivery schedules in time and space; and the term irrigation scheme performance as a measure of the net value of the agricultural production and the net positive social, economic and environmental effects or benefits derived from an irrigation scheme.

Management Needs

Irrigation involves both physical works and human activity. There is little need to discuss the physical irrigation system or the fact that human activity, such as management and the knowledge and effort to irrigate, are essential for success. A point that is often missed, however, is the need for communication between water users and suppliers so physical delivery and application of water can take place in a meaningful way. The management efforts of the various people involved and either an automatic anticipatory system or a responsive communication system are needed to tie irrigation scheduling decision-making and delivery processes together.

In addition to irrigation, for successful agricultural production, other physical

inputs such as seed, fertilizer, and pesticides are required at the irrigation scheme level. The delivery of all of the above must come together in an optimal mix at the individual plant as well as the field level in order to achieve high production. For production to be meaningful and sustainable, harvesting, transportation, storage and marketing are also necessary.

Experience has shown that many if not most irrigation systems and the schemes they serve have been designed with little regard for the social and political, as well as the engineering and agronomic aspects of both the management of deliveries and the efficient on-farm use of water. Typically, the quality of management, quantity and timing of labor, microeconomics, other needed agronomic inputs and marketing have received insufficient attention. This has resulted in many irrigation schemes, with "technically feasible" irrigation systems, falling far short of meeting expected production goals. In both developed and developing countries, improving irrigation scheduling and system management has the potential of increasing water and energy use efficiency by 20 to 50 percent. By improving both irrigation system and crop management, crop production per unit of water supplied to most irrigation schemes could be at least doubled in many developing countries.

Management Plan

Irrigation system or scheme management starts by defining purpose and the underlying objectives, for there is no management without objectives. Next, it delineates procedures to achieve the objectives and monitors selected performance parameters to see whether the objectives are being achieved or not. If the objectives are met, then the irrigation system or scheme is assumed to be well managed. Otherwise, in the case of an irrigation system, for example, appropriate changes in the system's parameters must be made in the planning, design, construction, operation and/or maintenance of the system. In addition to having a good management plan, the operating staff needs to be committed to the purpose of the undertaking.

For a new irrigation system, one can plan, design, and implement the system for manageability. For an existing irrigation system, however, the diagnostic approach for developing a new management plan starts with monitoring (or analyzing) the system performance and comparing it with the desired (or expected) performance. If the actual falls too far short of the desired performance, the factors responsible for the low system performance are delineated and solutions for improving it developed. The recommended solutions should be developed in consultation with the managers and users and first be tested on a pilot level before being fully implemented. Typical solutions involve modifications of planning, design, construction, operation and/or maintenance procedures.

Farmers who are the direct beneficiaries of public irrigation systems try to maximize their own "net benefits" from irrigation. They do this by maximizing the productivity per unit of land, labor, capital or water; whichever is their scarcest resource. However, for the more favorably situated farmers, water may not be the scarcest resource unless it is rationed, allocated, and distributed equitably, even if it is in short supply elsewhere within the irrigation system. Therefore, the favorably situated farmers may not be concerned about water-use efficiency or fair and equitable distribution of water to other farmers, although these are typical operational objectives for public irrigation systems. This dichotomy between the operational objectives of the public agency and the more favorably situated private beneficiaries is the root cause of many problems in managing irrigation systems.

Irrigation enterprises are not static, they are continuously evolving (or changing). Changes occur to move the system toward equilibrium. The rate of change is a function of the degree of a system's uncontrolled (unmanaged) instability. Three major types of changes are those associated with: the rate of physical deterioration relative to maintenance; the development of the support institutions and farmers; and the changes in economics, physical inputs, labor availability, techniques, technologies and the natural resource base. (These features and processes are typical of organisms.) Being physical enterprises operated and maintained by agency personnel and the farmers being served, changes take place in an ecologically rational manner and in accordance with the attractions or incentives and disciplinary actions relative to all the people involved. It would be "ideal" if we could devise a means for obtaining the desired irrigation scheme performance entirely through a positive approach by creating all the necessary incentives to stimulate development to meet specified objectives. Unfortunately, it is difficult to imagine devising such a development framework, and thus, the need for enforcement powers and discipline.

Some areas that are often overlooked in planning for better or improved irrigation system and/or scheme performance are:

- The need for sufficient communication between the users and suppliers of water so that the physical delivery and application of water can take place in a meaningful way;

- The need for visualizing irrigated agricultural development in an integrated interdisciplinary framework;

- The need for careful, well disciplined and responsive main system management capable of delivering water in a timely, efficient and equitable manner;

- The fact that irrigation systems with low relative water supplies require extensive physical works and diligent management to achieve equitable distribution and high water-use efficiencies;

- The evolving (or changing) nature of irrigation farmers, institutions, systems and schemes along with the need to create an environment which attracts as well as disciplines the process toward the desired ends;

- An appreciation for the three potential management levels and related physical interfaces of large irrigation systems serving numerous small farms which are: the water supply system, the farm application system; and the interface between them;

- The potential created by irrigation developments for reusing surface or subsurface drainage waters to increase the overall efficiency of water utilization through conjunctive use; and

- The need for: leaving room for flexibility and change when designing systems; a more integrated study curriculum for the technicians involved in system design and management; and a better understanding of the entrepreneurship and labor requirements of irrigated agriculture.

Good irrigation management requires conceptualizing and articulating purpose and generating the creative capacity using all available resources to increase organizational productivity in pursuit of its goals. However, most often the administrators assume or accept assigned objectives and use prescribed techniques to regulate, control and distribute (dispense) given resources in an effort to achieve them.

AN IRRIGATION SYSTEM/SCHEME OVERVIEW

As a beginning point, it appears that many irrigation systems and the schemes they serve are designed and implemented without having a clear concept of purpose. I can see four somewhat different objectives for irrigation development. These are: for commercial production; for sociopolitical reasons; for environmental reasons; and/or for geostrategic reasons. A commercial production objective refers to an irrigation development where the principal purpose is to produce food and fiber for markets. A sociopolitical (or social benefit) objective generally refers to a project which is principally directed to improving the well-being of a rather large number of existing or resettled farmers with small land holdings. By geostrategic, I refer to projects which are initiated as political favors or for regional development or security reasons. An environmental objective might be to provide more hospitable living conditions or to reduce flooding.

The purpose of most irrigation developments contain elements of more than one objective. Thus, the objectives must be ranked and integrated into a structural unity and clarified intent to reveal the purpose at the onset (rather than making all schemes appear to be commercially oriented using standard benefit-cost analysis). A clear statement of purpose is important for it provides an essential criterion for decision-making (between one course of action and another).

Domains of Irrigation Schemes

We find it useful to think of an irrigation scheme as having three primary physical/management domains; namely, the watershed domain, the water supply system domain, and the agricultural domain. Figure 1 shows a schematic depicting a water supply system receiving its water from the watershed and delivering it to an irrigated farm area. As a reminder that an irrigation scheme is only a part of the larger human and natural ecosystems, we have surrounded it by a three-sided box. We have purposely left the watershed end open because often much of it lies outside of any direct influence of the scheme managers yet the scheme is dependent on the watershed.

The water supply system includes: the dam and reservoir to capture and store water; the conveyance, delivery and regulating structures; and the drainage works. The water supply system plus the drainage and on-farm irrigation works make up the irrigation system. The irrigation system includes the entire water supply system domain but only part of the agricultural domain and practically none of the watershed. Thus, the scope of the irrigation system is considerably limited as compared to that of the irrigation scheme of which it is the key feature.

The lack of understanding and/or communicating this difference between the system and scheme perspectives has lead to considerable confusion and mismanagement of resources. Typically, irrigation agencies mainly focus on the irrigation water supply system (or, at best, on the entire irrigation system). Since water is not only essential but often the most costly and difficult to manage input to irrigated agriculture, this focus is necessary but not sufficient for scheme success.

Inputs

Since water is an essential input, "getting the hydrology right" is essential. In dealing with surface resources this is difficult because of the stochastic nature of watershed runoff and river flows. It is also difficult when dealing with groundwater resources because of the expense and inaccuracies associated with groundwater surveys.

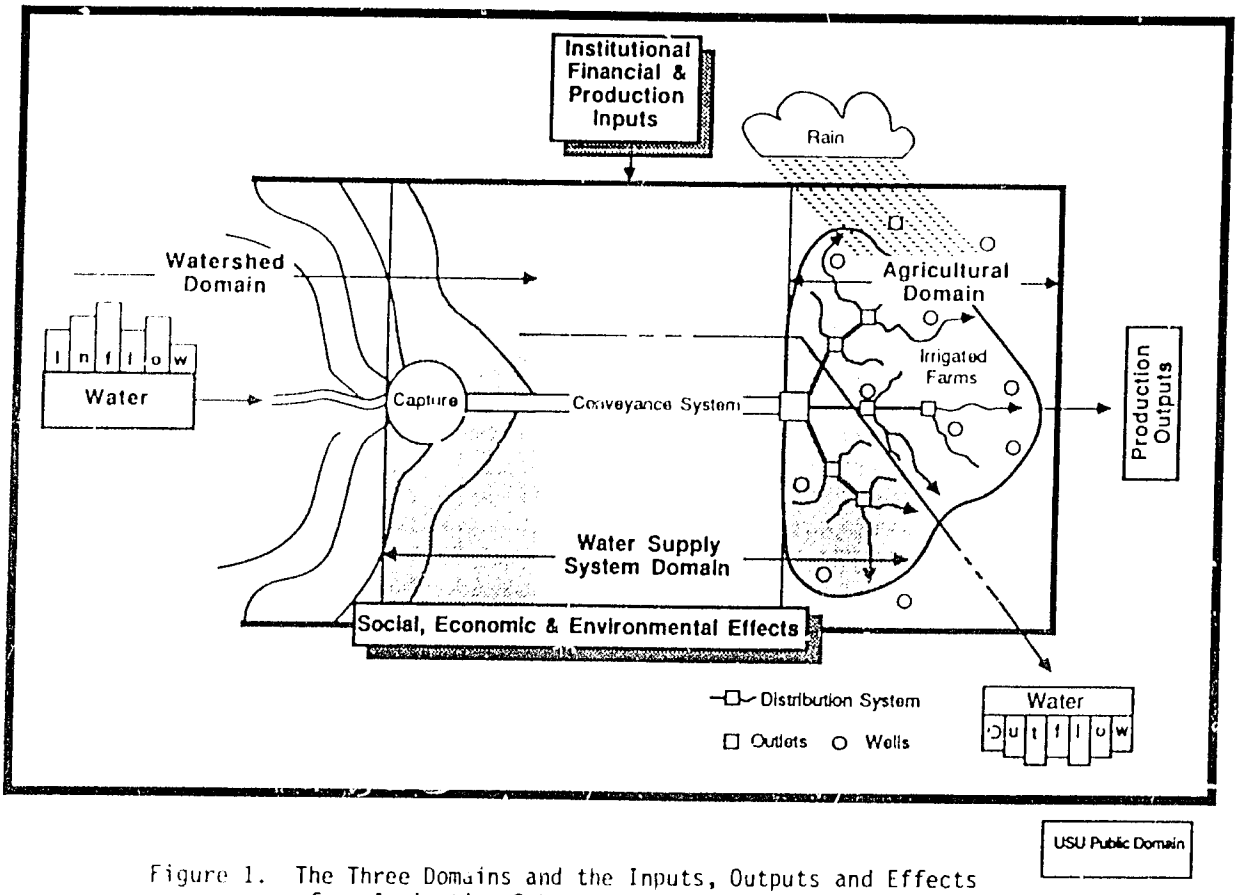

Figure 1. The Three Domains and the Inputs, Outputs and Effects of an Irrigation Scheme.

For schemes supplied directly from rivers, getting the hydrology right means first of all correctly anticipating (based on probabilities) the available inflow water and silt loads throughout the potential annual irrigation seasons (for sizing the irrigated farm area and anticipating silt removal requirements). For schemes supplied from surface reservoirs, it means both correctly anticipating (based on probabilities) the total expected watershed runoff and silt loads (for sizing the reservoir and irrigated farm area); and peak flows (for sizing the spillway for dam safety purposes). For schemes supplied from groundwater reservoirs, it means correctly anticipating the expected yield and drawdown of the wells over an extended period as well as during the annual irrigation seasons (for sizing the irrigated farm area and estimating energy costs).

In addition to the above, getting the hydrology right also means correctly estimating irrigation water requirements (plant water needs less effective rain, see Figure 1) for some "reasonable" cropping patterns and expected irrigation system performance. Unfortunately, to satisfy standard benefit-cost analysis criteria, planners often distort the hydrology by overestimating water supplies, irrigation system efficiencies and crop productivity. Furthermore, there is also a tendency to select cropping patterns and operating rules which leave too little flexibility for future change.

Along with water, sunshine and the atmospheric environment, a number of institutional, financial and production inputs from sources external to the scheme are essential for irrigation scheme implementation and success such as:

- Labor, techniques and technical skills;

- Information about crop selection, husbandry, protection and management;
- Management in all three domains;
- Capital (money) and credit;
- Irrigation system and farming equipment, technologies and supplies;
- Power or fuel (energy) to operate the irrigation system and farming equipment;
- Transportation and communication devices; and
- Other needed infrastructure.

Internal Resources

The farmers along with their lands commanded by the irrigation systems (within the boundaries surrounding the water supply system and agricultural domains in Figure 1) make up the primary internal resources of an irrigation scheme. The individual and collective capabilities of the farmers and the quality of the land greatly affect both the gestation period and the ultimate success of irrigation development.

Potential secondary internal resources include the local institutional structures, labor supplies, local sources of capital and traditional irrigated agricultural technologies and techniques. Important institutional structures (which are often overlooked) include: traditional community management organizations; local organizations for communicating and transferring information and knowledge; and local credit, transportation and marketing structures.

Outputs and Effects

Irrigated (as well as rainfed) agricultural production is the major scheme output. Often, much of the irrigated production from gravity-flow systems is dependent on water lifted from wells and/or drains which in turn are recharged by the gravity systems. This reuse of "lost" water is called conjunctive use and it should be taken into account in determining benefits. For an irrigation development to be an economic success, there must be ample marketable production to recover at least part of the capital costs as well as recurring and rehabilitation costs of the irrigation system.

In addition to production outputs, there will be some outflow water plus some beneficial and some adverse "social, economic, and environmental effects" resulting from developing an irrigation scheme (see Figure 1). The outflow water resulting from reservoir spills and releases plus channel seepage, operational losses and excess irrigation applications may be good or bad depending on its quality (salinity) as well as temporal and spatial quantity. Before making system changes designed to reduce water losses from a mature gravity-flow system, the benefits being derived from conjunctive use within the system and from outflow waters should be carefully considered.

Figure 1 shows the institutional, financial and production needs for the scheme as inputs from the larger human and natural ecosystems of which it is a part. The production outputs are deliveries to this larger universe. But the social, economic and environmental effects of the irrigation development are symbolically shown as being both internal and external to the scheme by overlapping the three-sided box surrounding the scheme. Typical beneficial social, economic and environmental effects of an irrigation development might be:

- Labor benefits;
- Increased tax returns;
- New fisheries;

- Recreation opportunities;
- Reduced flooding and erosion;
- More stable groundwater and downstream irrigation water supplies;
- Improved domestic water supplies;
- More reliable and nutritious food supplies, better income distribution and improved living standards for more people;
- Increased commerce and incomes in adjacent regions, etc.

Typical adverse effects might be:

- Waterborne diseases;
- Health hazards related to chemical (such as insecticide) inputs;
- Displaced farmers from the submergence and canal right-of-way areas;
- Loss of downstream riparian domestic and irrigation water rights;
- Loss of recession agriculture lands and related silt deposits which improve the soil;
- Destruction of traditional river and estuary fisheries;
- Salt water intrusion in estuaries;
- Labor shortages in adjacent areas;
- Depressed commodity prices due to excess production;
- Political and social conflict and corruption;
- Inequitable income distribution due to uneven access to water;
- Real estate speculation in the command area, etc.

Project Planning, Design and Management

The job of good irrigation development planning, design, and management requires minimizing negative effects to the human and natural ecosystems and unproductive inputs while producing sufficient net benefits to offset costs. To do this, the value of both production outputs and beneficial effects must be sufficient to offset the monetary and other societal costs of both the inputs and adverse effects.

For the watershed domain, this requires getting the hydrology right in the first place, as discussed earlier. It also requires managing the watershed to the extent possible to both: maintain its performance in terms of runoff reliability and sustainability by restricting development of upstream water consumption; and minimize silt loading by encouraging erosion control practices and activities such as reforestation, managed grazing, conservation farming and building erosion control structures.

To effectively manage the water supply system, the entire conveyance/ distribution (delivery) system and the discharges from the outlets provided to serve the farm units must be predictable. As a first step following construction, this requires hydraulic performance testing from the headgate to each field turnout (see Figure 2). This initial testing is necessary to determine the as-built performance and pinpoint major design/construction flaws needing correction. (Hydraulic performance testing is the practice of measuring and recording flow rates at strategic locations throughout the entire system under all normal operational modes.) Thereafter, periodic testing is necessary to monitor on-line performance and determine maintenance and/or rehabilitation needs. To be predictable, outlets must either be controlled (or fixed) flow devices or be adjustable and provided with some means for measuring the discharge flow. For the

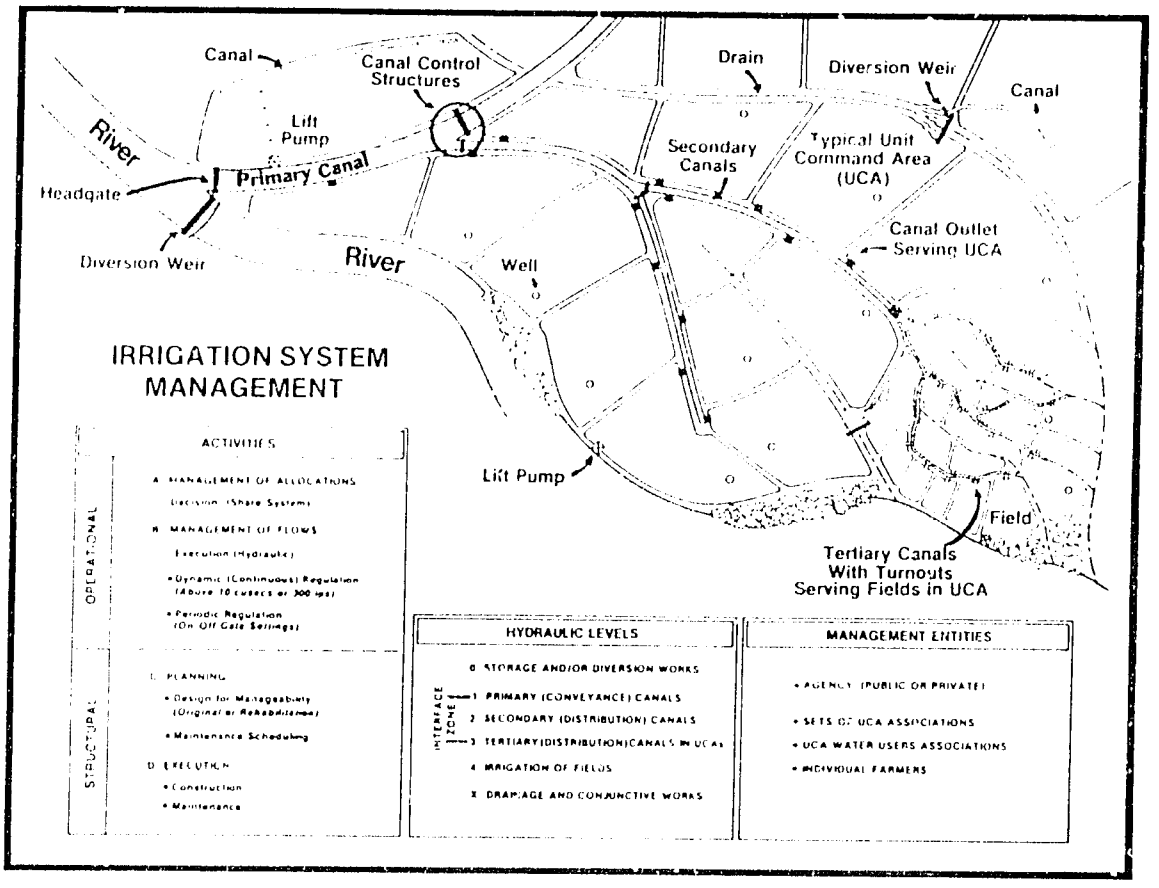

Figure 2. Pictorial Sketch Showing Common Elements with an Outline of Management Activities, Entities and Hydraulic Levels for a Large-Scale Canal Irrigation System.

smaller outlets along the secondary canals serving individual or groups of farmers, controlled flow devices are preferable.

To most effectively serve all the irrigated farms in the agricultural domain, the water supply must be reliable, predictable, timely, and accessible to each farm unit. Furthermore, it is usually intended that the water be equitably distributed among all of the farms commanded by the irrigation system. To achieve these lofty goals, the water supply system from the headworks to the controlled outlets serving the unit command areas (UCAs), which make up the "top or upper end" of the irrigation system, must be well planned, designed, constructed and managed. In addition, properly planned and designed tertiary canals and field channels must also be constructed within the UCAs to convey the irrigation water to within practical reach of each farm field. (See the tertiary canals with turnouts serving fields in the large UCA in Figure 2.) To do this effectively and give all farmers access to their share of water and a sense of ownership and commitment to the system (especially the shared canals within the UCAs) requires consultation and collaboration with and between the farmers.

Getting the water to farmers' fields is still not enough, for it must be properly applied (along with other inputs in the agricultural domain) to become fully productive. To properly apply water to the fields requires having a reasonably good physical application system with sufficient labor and knowledgeable management to

operate it. However, farmers often lack the incentives, resources, time and/or knowhow to complete and adequately manage this "bottom or lower end" of the irrigation system. So, even if the irrigation water delivery system works to perfection, the irrigation scheme may fail for lack of production unless farmers are provided with or have the necessary technical assistance, credit and/or incentives.

In addition to delivering and applying water, excess surface and subsurface waters must be drained away to minimize waterlogging and salinity. Within larger irrigation systems, water delivery and the removal of excess water are usually the job of the irrigation bureaucracy. Fortunately, (both private and public) wells within the irrigated areas (see Figures 1 and 2) play a duel role by augmenting the quantity, reach and timing of surface water deliveries, while at the same time reducing or even eliminating the need for additional subsurface drainage.

The agricultural domain is where the scheme's main productive value is generated. To optimize production, a complex set of production and institutional inputs (such as seeds, fertilizer and chemicals, irrigation and crop husbandry knowhow, various other technologies, irrigation and cultural equipment, labor, energy and management) in addition to water must be available and brought together in an effective and timely way. For large schemes serving numerous small irrigated farms, this is no easy task as it requires consultation and cooperation within and between many farmers as well as with various public and/or private agencies. These agencies must also consult and cooperate with each other as well. In addition to the departments representing irrigation, research, production and extension, other departments or enterprises such as those associated with rural development, groundwater development, electric supply, transportation, marketing and retail farm supply should also be included. Command area development agencies made up of professionals representing the irrigation and various other departments have been tried as one means of obtaining some of the needed interagency cooperation. Water user groups of various configurations are often promoted as a means of institutionalizing farmer cooperation for maintaining and managing the lower reaches of the water supply system (within the UCAs) as well as for acquiring other needed farm inputs, information and services.

Management in Domain Overlaps

In Figure 1 (which depicts a large irrigation scheme) the domain of the water supply system is overlapped by both the watershed and the agricultural domains. Symbolically, the principal areas of overlap are depicted by the shaded areas; but the watershed may actually overlap the entire irrigation system. Furthermore, the agricultural domain may overlap the entire water supply system especially where pumping from the conveyance systems is allowed. Two important happenings may take place in the watershed overlap: surface drainage and side inflows from the watershed may directly affect the water quality and quantity as well as the safety and silting of the reservoir, dam spillway and delivery system; and animal or human activities may encroach upon and damage the above works.

Managing irrigation system operations requires a decision followed by an execution phase. The decision as to how much and where to allocate the water and when to deliver it must be made first. This is essentially a bottom (or farm) up process because the objective is to satisfy crop water requirements and equity issues. The execution phase requires managing the flows throughout the irrigation system from the top (capture) all the way down to the plants roots, because water flows downhill. In other words, for managing an

irrigation system, deciding what to do is a bottom to top process; deciding how to do it involves scheduling flows and gate settings simultaneously throughout; but doing it begins at the top. This bidirectional process requires collaboration and cooperation between the farmers and the agency managing irrigation system operations in order to meet the needs of the agricultural domain.

The overlap of the water supply system with the agricultural domain is complex because it is here the managers attempt to equitably allocate and distribute the water and satisfy the individual and collective requirements of the users. Within large systems (see Figures 1 and 2) serving many small farm units, the communication and responsiveness needed between the individual farmers and the irrigation agency to accomplish this is quite difficult and/or expensive. Therefore, the development of water user groups or associations in each UCA is encouraged. They provide an intermediate or middle management system so water can be discharged (through the controlled outlets of the water supply system) to each UCA (rather than to the individual farmers) and the water user groups can allocate it among themselves (to their individual fields). For water user groups to be successful, the water allocations should be based on a share system which is accepted as being equitable by the farmers as well as by the bureaucracy. Furthermore, unless there is significant community accord and cooperation, the water share system must also be based on rather rigid rules with explicit water rights backed by some authority (or law) with enforcement powers.

System Size and Complexity

Large-scale water resources such as major rivers usually require constructing large irrigation systems to fully develop them. Because of their size and technical complexity, the resulting large water supply systems must be managed by a public or private agency to serve the farmer clients. Furthermore, since water is such a vagrant element, keeping track and controlling it from the head to the many and varied* tail reaches of a large water supply system is a difficult task. This is particularly true where project development objectives call for stretching a limited water supply to only partially irrigate a large set of farms in an equitable and effective manner.

I have found it useful to think of the management function of delivering water uniformly to each farm in the irrigated command area like stretching a membrane over the area. Thus, I imagine that the more limited the water supply is in relation to the potential on-farm requirements (or demand), the greater the tension will be in the membrane. Holding the tension necessary to keep the membrane uniformly stretched across the various and diverse societal groups usually involved is not easy. It requires: a workable operational plan; capable and disciplined administration of it; and careful design, construction, and maintenance of the water supply system. Finding these structural elements and institutional capabilities in combination is rare indeed. Thus, the performance of large irrigation schemes is often disappointing even where the farmers have the incentive and capacity to properly irrigate their fields and all the other necessary agricultural inputs are available.

When the physical system and/or its management are not sufficient to stretch the water over the full length and breadth of the water supply network, the tension relaxes and the water ends up in globs, usually in the head reaches. Overwatering and/or growing crops with high water

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*There is a head (or inlet) and a tail (or terminal) end for each hydraulic level, i.e., main, secondary and tertiary, of a canal system.

requirements become standard where water supplies are ample; but this is done at the expense of shortages in main, secondary, tertiary and farm channel tail reaches* where water may seldom flow. Fortunately, supplying small irrigation systems from wells (see Figures 1 and 2) or from drains within (or adjacent to) large irrigation command areas somewhat mitigates the above inequities, although such conjunctive use is usually not part of the original planning but an afterthought.

In view of the above, it is not surprising that irrigation professionals have been more favorably impressed by the performance of small- as compared to large-scale gravity flow irrigation systems. The better performance results from: the reduced institutional complexity; the use of more local human and physical resources (instead of external resources); and the greater social cohesiveness associated with managing small systems. Looking at Figure 1 it is easy to visualize that if the water supply system is shrunk far enough it will all end up in the agricultural domain. Shrink it still further and it will end up as a few outlets serving a relatively small group of farmers. Such small-scale systems have traditionally been built, maintained, and operated by groups of farmers using local resources and techniques where there is a suitable source of water.

Ultimately, if the system is shrunk far enough it will end up as a very small system in the domain of a single farmer (or only a few farmers), and much, if not most of the institutional and social complexity of managing large gravity irrigation systems vanishes. Unfortunately, many small-scale systems and most very small irrigation systems require lifting water from wells or surface sources. The lifting devices and fuel required to operate them (except in the case of hand-lifting) adds considerably to the complexity and out-of-pocket expense of operation. Furthermore, serving the energy, repair and maintenance requirements of many small lifting devices may also require a complex network, such as an electric grid or liquid fuel delivery system and engine repair services. In addition, unlike gravity flow systems, irrigation systems relying on pumps require disciplined systematic maintenance with an almost continuous flow of fuel and other cash inputs for uninterrupted operation.

Where there are many small-scale or very small irrigation systems operating from a common aquifer or surface source, the collective set of systems along with the watershed and agricultural domains may make up an "irrigation scheme." Such an irrigation scheme may be theoretically more complex to manage than one encompassing a single large irrigation system. But, we favor sets of smaller systems because of the vitality afforded by having many management units which are relatively independent of outside influence and perhaps are even controlled by the farmers themselves. In fact, this argument has led to an interesting suggestion for improving the performance of schemes relying on large water supply systems. That is, to implement and manage the large-scale system in such a way that it becomes a predictable and reliable source of water for a set of independent small-scale subsystems.

The lesson from the above is: use sets of the smallest economically viable irrigation systems which are collectively capable of adequately exploiting the available water resources. One important exception to the lesson is: when economically feasible, use a larger irrigation system which depends on gravity flow in place of a group of smaller irrigation systems which require pumping.

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*There is a head (or inlet) and a tail (or terminal) end for each hydraulic level, i.e., main, secondary and tertiary, of a canal system.

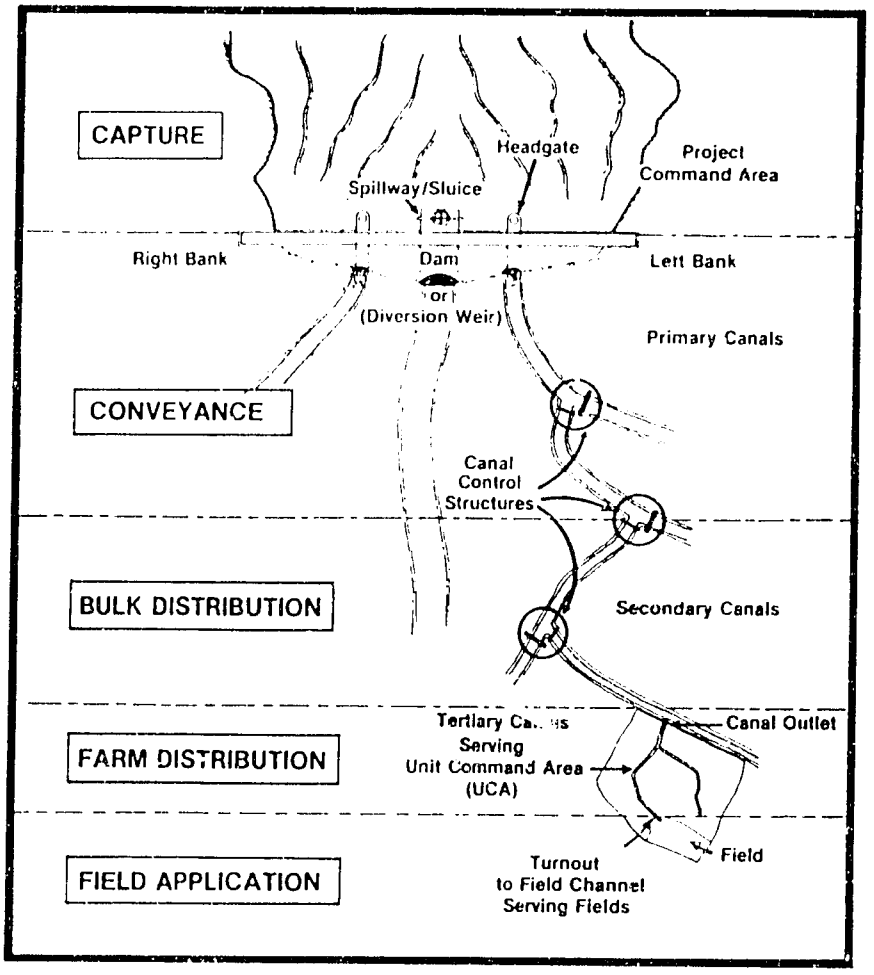

Figure 3. The Various Levels of Channels Serving a Large-Scale Canal Irrigation System.

MANAGING LARGE-SCALE CANAL IRRIGATION SYSTEMS*

Typically, the principal overall management objective of an irrigation system is to provide timely irrigations to maintain optimum crop production consistent with the non-manageable constraints. (The overall management involves the bureaucracy, the farmer organizations and the farmers.)

Physical Structures

All canal systems follow the same general hierarchical tree-like structure (see Figure 3). The principal differences of configuration among systems are:

- Size: There are more hierarchical levels in large systems;
- Canal infrastructure: Generally, the length of farm distribution channels per unit area served increases as the size of fields decreases (except in the case of paddy-to-paddy distribution); and
- Regulation and control structures: These are influenced more by the vertical hydraulic dimensions than by the plan (or horizontal) dimensions.

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*Note: Much of the material in this section is based on Reference (6).

Paddy and Upland Systems: A main subdivision can be made between systems serving paddy (rice) and systems serving upland crops. There are large differences between the water delivery and application strategies or techniques which are appropriate for flooded paddies and those appropriate for upland crops. With flooded irrigation it is possible and practical to use some field-to-field irrigation between paddy fields as part of the conveyance system. Water may be allowed to flow from paddy-to-paddy without materially effecting the area of land that can be kept continuously flooded. It is only during prewetting and when the water supply is limited and paddies are allowed to dry out between irrigations that management difficulties arise from using paddy-to-paddy water delivery.

Another attribute of paddies is that precise land leveling is less important than for basin or other surface irrigation methods. This is because it is not important to maintain a uniform depth of water in a paddy as long as it is kept fully flooded. Furthermore, where continuous flooding is practiced, scheduling paddy irrigation is relatively simple. The paddies only need to be kept flooded, compensating for losses to evapotranspiration and deep percolation. Scheduling irrigations for upland crops is more complicated because changing soil water holding and root depth characteristics must be taken into account along with changing crop water requirements.

With upland crops, it is obviously impossible or impractical to use field-to-field delivery systems. Thus, more tertiary canals and field channels or other conveyance means are needed. Managing the farm distribution and field application systems (see Figure 3) along with irrigation scheduling is where the notions of "farm water management" become critical.

System Components: A corner of a large-scale irrigation system is shown in Figure 2. The water supply system begins with the diversion weir on the river which diverts water through the headgate into the primary canal. Control structures along the primary canal divert part of the water into the secondary canals (or bulk distribution system). These in turn distribute water through controlled outlets to tertiary canals provided with turnouts to distribute it to a group of fields. As mentioned earlier, the area served from an outlet is often referred to as a unit command area (UCA). The uppermost UCA requires a lift pump which supplies water to a small channel along its upper edge. It can function somewhat independently from the rest of the water supply system, and thus might be thought of as a small-scale system appended to the main system. While it is not desirable to have a UCA served by gravity directly from the primary canal, this is the only practical possibility for serving the small triangular UCA near the headgate (see Figure 2). Outlets along the secondary canals form a more orderly part of the layout.

In addition to deliveries from the main water supply system, a number of wells scattered throughout plus small lift pumps which take water directly from the river and small diversion weirs on the drains also supply irrigation water to the command area. The small diversion weir (on the upper drain in Figure 2) and canal could function as a community-operated small-scale irrigation system. Its water supply, while dependent on drainage from the main water supply system, is not controlled by the main system managers. The wells scattered throughout the UCAs and the small river lift pumps are most apt to be under individual or collective private ownership and control, and thus are also independently managed.

Because of topographic considerations, it is not possible to have all the UCAs more or less the same size. For example, the largest UCA, which is shown complete with tertiary channels and field boundaries

(in the lower right corner of Figure 2) covers three or four times as much area as the smallest UCA shown. Thus, the quantity of water delivered to each UCA must be adjusted accordingly.

Figure 3 shows a pictorial sketch depicting the various levels of channels serving a large-scale irrigation system. The purpose of presenting the pictorial sketches in Figures 2 and 3 and the above discussion is to point out the rich diversity of physical layouts of gravity irrigation systems and a common set of nomenclature. Of particular interest are: the different ways which UCAs are serviced from the main water supply system; the variations in sizes of UCAs and in the fields within them; the fact that topography and drainage considerations play an important role in the irrigation system's structure; and the intermix of independently operated small systems relying on conjunctive use from wells and drains to augment the main system.

Hydraulic Levels: In a large-scale irrigation system there are six distinct hydraulic levels as depicted in Figures 2 and 3. These are:

0 • A dam, diversion weir or well field to capture the irrigation water supply;

1. Primary canals, whose principal function is conveying large volumes of water;

2. Secondary canals, which provide the bulk distribution of water to the outlets serving UCAs;

3. Tertiary canals in the UCAs with turnouts which serve the individual farms or fields within the UCAs; and

4. The conveyance and application of irrigation water on the fields for use by the crops; plus

X • An above and below ground drainage system to remove excess water.

While large-scale systems typically have all six of these levels, very small systems may have only three, and small-scale systems four or five of them (as discussed previously). For example, individual fields may be supplied directly from small wells. In small-scale community irrigation systems (supplied by small lift pumps or gravity diversions), water may be supplied directly to the small canals serving a UCA, or through a small primary/secondary canal system serving a few UCAs.

Management Entities

Irrigation enterprises have at one end, the water supply system made up of the hydraulic collection and delivery systems; and at the other end, the agricultural domain with individual farmers and their fields and other farm production facilities (see Figure 1). In most developing countries, the organization responsible for the main water supply system delivers water to UCAs not to individual holdings. Thus, there is a middle zone of collective responsibility for dealing with water distribution within the UCAs.

The following four basic management entities (see block--lower right of Figure 2) may potentially be involved in managing large-scale irrigation systems:

- The public or private agency responsible for the main water supply system. (This represents that portion of irrigation management which is basically detached from the agricultural domain;)

- Sets of UCA water user associations;

- Formal or informal UCA water user associations or community management groups; and

- Individual farmers.

Obviously, all systems must have individual farmers. On larger-scale systems there is usually an agency involved and, even if the farmers are not organized into formal associations or groups, in one way or another they must work together.

Water User Organizations: It is often considered desirable to have a formal water user association for each UCA. The organizational process is typically based on some sort of enabling legislation. Through field research studies and demonstrations, Uphoff (6) developed a workable procedure or model for organizing farmers, but it cannot be duplicated or copied in the "copy machine" sense. Some generally overlooked criteria in his model for developing successful water user organizations include:

- Employing special outside professional organizers to assist with the organizing process;
- Selecting a representative by consensus of the farmers in each UCA and keeping politics out, as political posturing tends to create conflict which ends up undermining the water user organizations;
- Tying the organizing process to the development or improvement of physical works to serve as a catalyst for organizing the farmers; and
- Setting up the organization during the construction phase of new systems, or as an integrated part of the rehabilitation process of old systems.

For larger irrigation systems he found it useful to amalgamate the water user associations into sets of UCA associations to assist in management activities related to the bulk distribution of water at hydraulic levels of the system above the UCAs (see Figure 3). Such sets of UCA associations are typically made up of elected representatives from each UCA water user association and make their decisions democratically.

Hydraulic Levels and Management

The activities related to irrigation system management can be broken or divided into those related to the operation of the system and those related to the structural elements of the system (see "Activities" block--left bottom of Figure 2). At any given point in time, the real time management of flows involves operating the system in whatever structural configuration and state of repair it happens to be in. The hydraulic levels described earlier have different management entities associated with them. However, the various management entities do not necessarily need to have the same operational and structural (or maintenance) responsibilities for each of the hydraulic levels.

Operational Activities: The principal operational activities are: management of allocations, which is the decision portion of the management activity; and management of flows to satisfy the allocations, which is the execution activity. The configurations of the management entities dealing with allocations and flows may differ. For example, farmer groups may decide on allocations and agency personnel regulate the flows.

The management of allocations is either formally or informally based on a share system. The share system involves both the basis for the right to water and an assessment of the obligations associated with it. The three basic types of shares as outlined by Freeman (6) are:

- Shares by fixed percentage based on land area, flow rate and delivery time;
- Shares by priority based on location (e.g., head to tail), farm attribute (e.g., time of settlement) and crop (e.g., economic value); and

- Shares by dedicated rights or user demand from surface storage, drain flows or groundwater storage.

It is possible to combine share types by:

- Constraining one by another (e.g., volume constrained by crop priorities);

- Employing two types simultaneously (e.g., time rotation supplemented by higher-priced demand water); and

- Change types within season (e.g., shares by volume shifted during drought period to shares by crop priorities).

Once the decision has been made in absolute terms, or by default, the next operational step is the management of flows of water to best satisfy the allocation decisions.

To manage the flows in the larger portions of large-scale water supply systems (above ten cusecs, or 300 lps), dynamic (or continuous) regulation of flows is preferred. Dynamic regulation means manipulating the canal control structures in such a manner that the flows and/or water levels in the secondary canals (see Figure 2) are nearly constant. Dynamic regulation is only important in the upper portions of large delivery systems in which the lag times between when the water enters the system and reaches the distal points is rather long (over 6 hours). Without dynamic regulation, the water elevations (levels) in the secondary canals continuously change, and consequently, the flows (or bulk distribution) through the canal outlets serving the UCAs will vary considerably. Thus, the quantity of water supplied to the UCAs is not predictable (or dependable) which, in turn, reduces the value of the water to the farmers, and their willingness or desire to pay for it and use it efficiently.

In the portions of the system where flows are relatively small and the lag time is short, periodic regulation using on-off gate settings is most appropriate. Periodic regulation does not imply that relatively frequent gate changes are not made, but rather that fixed gate settings are used and typically the gates are either fully open or completely closed.

Structural Activities: The structural management activities are outlined in the lower left-hand corner of Figure 2. Management of construction and maintenance requires a decision (or planning) phases followed by the actual execution of the work involved. The management entities responsible for each operation or structural activity in both the decision and execution modes can and probably should differ depending on the local circumstances. Through research activities led by Walker (6), powerful computer models have been developed to improve main system management. While this new hydraulic modeling research is directed at operational activities, the models and insights gained from their application should be useful in designing both new and rehabilitating old water supply systems for ease of operation and better management of allocations and flows.

Interface Zone: An "interface zone" is depicted in the "Hydraulic Levels" block at the bottom of Figure 2. This is where the domain of the water supply system and the agricultural domain overlap in Figure 1. In this zone the different management entities are responsible for and interact in various ways while carrying out the various structural and operational activities. The interface is that "middle management zone" between the individual users (irrigators) and the bulk distributor (irrigation agency) of water. The question is, Will this be a battle zone with efforts being made by the agency to control from above, or a collaborative zone supported from below by the irrigators in which negotiations are made to mitigate conflicts arising from adjusting demands in view of estimated supplies?

Findings to date suggest that rehabilitation of poorly perfonning irrigation systems is not simply a matter of reconstructing physical facilities to handle water deliveries more effectively. It is also a matter of examining defects in the management activities in the interface zone to determine why the water could not be delivered in sufficiently controllable ways so as to earn the full support of the irrigators. It appears that an essential part of large-scale irrigation system management will require building improved organizational arrangements linking the individual irrigators and the managers of the water supply system.

Management Intensities: There is considerable interest in management intensity as it relates to irrigation system performance. Increasing management intensity means both hardware inputs (such as lining channels, extending canals, augmenting surface water supplies with groundwater, improving control and measurement structures, etc.), and software inputs (such as organizing farmers, using computer-aided dynamic canal regulation, training to improve management skills, improving communications, etc.). Studies have been conducted on management intensity by Barker (6), but the results to date, in terms of cost-effectiveness, are varied. Thus, rather site specific analysis on a case by case basis is still required to determine the relative value of various management interventions.

CONCLUDING COMMENTS

I think of the principal purpose of irrigation development as being to increase the freedom of choice for (or well-being of) the community of users and other beneficiaries directly served by an irrigation scheme. For successful development this must be done without jeopardizing the freedom of choice for the larger community of which the scheme is only a part.

We should plan projects that satisfy the policy objectives and goals based on designs that are realistic in terms of resources and other constraints. The engineers and agronomists usually do quite well at designing projects so they are functional in a physical sense. They adapt them to the physical resources and constraints. But, for the most part, we (collectively) do very poorly at designing manageable systems for the agencies and users who must live with the schemes and make them work. Even after rehabilitation a scheme may still have little chance of being successfully operated unless adequate attention has been given to the physical, behavioral and economic contexts.

In general, good management is the business of doing what is wanted (by both the direct beneficiaries and larger community) in the best manner possible with the resources available. Irrigation system or scheme management starts by understanding the purpose, then ranking and defining the necessary objectives. Next, it delineates procedures to achieve the objectives and monitors selected performance parameters to determine whether the objectives are in fact being achieved. If they are, the system or scheme is assumed to be well managed, if not, appropriate corrections should be made.

Looking closely at those parts or aspects of an irrigation enterprise that appear to be working well is very important when searching for ways to improve scheme perfonmance. This is because what is being done well is probably what people are contented in doing. From my observations, studying what is being done well provides insights about the values which the people involved are responsive to in the physical, economic and cultural environment where the scheme is situated.

The idea of focusing on what is right and identifying positive opportunities for improving performance when analyzing

Table 1. Alternate Analytical Approaches for Finding Ways to Improve Irrigation Performance.

OPPORTUNITY ANALYSIS (a management/experts approach)*	DIAGNOSTIC ANALYSIS (a clinical/specialists approach)
1. Focuses on what is right, i.e., opportunity identification--a positive approach.	1. Focuses on what is wrong, i.e., problem identification--a negative approach.
2. Assumes what is happening is rational within an understandable ecological/behavioral/economic context.	2. Assumes and tests for problems based on disciplinary perspective of what is right, expected or desired.
3. Tries to understand the context within which the whole system is functioning and how to improve it.	3. Tries to determine the priority constraints/problems or what is wrong with the system and how to fix it.
4. Searches for strengths or what is workable and hence wanted by examining what is working and successful.	4. Searches for weaknesses or what has failed or is not working according to standards of the disciplines.
5. Appreciates local values that are needed to have locally acceptable development.	5. Imposes preconceived values as solutions and tries to enlist local support.
6. Takes a performance view, i.e., coach to improve performance.	6. Takes a clinical (sickness) view, i.e., physician to heal patient.
7. Need/result oriented, i.e., searches for most cost-effective changes or assistance.	7. Supply/method oriented, i.e., searches for opportunities to supply remedies for perceived constraints.
8. Requires an integrated framework leading to interdisciplinary action.	8. Requires a set of disciplinary frameworks leading to multidisciplinary action.
9. Falls within domain of consultation.	9. Falls within domain of prescription.

* This could also be referred to as an ecological/behavioral approach.

irrigation schemes is inherently overlooked by diagnostic approaches. By their nature, diagnostic analysis approaches concentrate on identifying problems. I have found it most productive to follow a positive or opportunity analysis approach when analyzing irrigation schemes. A comparison between the opportunity and the typical diagnostic analyses approaches is presented in Table 1.

Carrying out the two approaches is similar in terms of team make-up and reconnaissance activities, but they deviate significantly as opportunity analysis follows an ecological/behavioral rather than a clinical approach to the analysis. Working with available resources to get more effective and efficient performance toward an accepted purpose or goal is where our creative genius gets tested. For engineers, an opportunity analysis requires focusing on opportunities for cost-effective changes that will improve overall scheme performance; whereas, a diagnostic analysis tends to focus on problems or fixing what appears to be broken or not functioning.

Often the words system, scheme, project and enterprise are used interchangeably when referring to irrigation, but I find this confusing when communicating about irrigation development. This confusion extends to the management arena and I believe this is an important factor leading to poor irrigation performance. That is why I have endeavored to provide a clearer conceptual framework for thinking and communicating about irrigation management.

In my view, the three pictorial sketches which have been presented are of primary importance. Figure 1 was presented to help in conceptualizing:

- That the irrigation works (which make up the irrigation system) are only a part of an irrigation scheme;

- The watershed, water supply system and agricultural domains of an irrigation scheme;

- The inputs, outputs and effects relative to an irrigation scheme; and

- The dependency of irrigation schemes on the larger human and natural ecosystems of which they are a part.

Figures 2 and 3 which depict portions of large-scale gravity irrigation systems were presented:

- To depict the rich diversity of their physical layouts;

- To outline the potential hydraulic levels and management entities and activities or irrigation systems in general; and

- To provide a common set of nomenclature for them.

An individual large (or sets of smaller) irrigation system(s) has been defined as serving or supplying an irrigation scheme. The irrigation system includes the water capture, conveyance, distribution, application and drainage works; thus, managing the system involves managing these works or facilities. Managing the irrigation scheme involves a broader view, for it includes managing the watershed and the entire set of other activities related to the irrigated agricultural enterprise as well as the irrigation system (see Figure 1).

Unlike industrial systems or utilities, irrigation schemes and the irrigation systems serving them should be managed from the bottom upward, as well as from the top toward the bottom. This is necessary because the very act of irrigation requires farmers to be entrepreneurs and take risks. Farmers are not employees on the "payroll" but must gamble their time, capital, and talents in the real present, in hopes of accruing future benefits from the crops they produce. Because of this, a purely top-down management system is not generally effective, since the agency and its employees are not fully informed of farmer needs and do not take the risks.

To achieve the hoped-for results of irrigation development requires some alteration of the viewpoints and knowledge levels of everyone concerned. This includes the national politicians, the financiers, the planners, the designers, the contractors, the managers, the local politicians, the research and extension services, the agro-business suppliers, the farmers, the marketing people, and, perhaps most important of all, we professionals, who are involved in technology transfer and the irrigation development program. Hopefully, the concepts and isual frameworks presented herein will help sharpen the focus on improving irrigation performance worldwide.

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