THE CRITICAL ROLE OF IRRIGATION "LEARNING" AND IMPROVED SYSTEM PERFORMANCE IN MEETING FUTURE WATER AND FOOD DEMANDS

by

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ABSTRACT

Growing populations, increasing food demands, rapid urbanization and slowly but steadily rising industrialization efforts all portend tremendous competition for water. The situation in many cities has become deplorable. Irrigated agriculture is expected to satisfy much of the increased demand for food, but the physical infrastructure is deteriorating in many countries; thus, the diversion of irrigation water to cities will result in decreased food production. This dilemma can only be solved by continually improving the performance of existing irrigation systems, so that small reductions in available water can be compensated by improved management practices that will result in increased agricultural productivity. Yet, in so many cases, those who are responsible for the performance of irrigation facilities and organization lack the managerial and institutional capability for achieving continued improvements. Learning processes are needed that provide guidance in adapting appropriate solutions to the site-specific situation of each irrigation system, with the "learning" involving all parties, including irrigation and agriculture agencies, but especially farmers. This "learning" should lead to the creation of "visible" success stories that provide a viable regional model for irrigation development.

RÉSUMÉ

Dans le contexte actuel d'accroissement démographique et d'augmentation de la demande en produits alimentaires, d'urbanisation rapide et d'industialisation, l'eau est l'objet d'une compétition de plus en plus intense. La fourniture en eau potable dans de nombreuses villes est devenue alarmante. Le transfert d'eau d'irrigation vers ces villes pourraient résoudre ce problème, mais serait contraire à l'objectif principal du secteur de l'irrigation, i.e. produire plus pour répondre aux besoins alimentaires croissants de la population, et ceci, malgrè des infrastructures qui se détériorent dans de nombreux pays. Pour résoudre ce dilemne, une amélioration constante de la performance des périmètres irrigués existants est nécessaire. Des réductions même marginales des quantités d'eau allouées aux périmètres irrigués pourraient ainsi être compensées par les gains de productivité d'une gestion améliorée de ces périmètres. Malheureusement, dans de nombreux cas, les capacités de gestion et d'organisation à la base de ces améliorations semblent être réduites ou tout simplement absentes. Des processus d'"apprentissage" sont nécessaires pour obtenir des solutions adaptées aux situations locales charactéristiques de chaque périmètre irrigué. Cette phase d'"apprentissage" concernera tous les acteurs impliqués dans la gestion des périmètres, mais plus particulièrement les exploitants agricoles eux-mêmes. Elle devrait conduire à l'identification d'approches réussies qui fourniront des modèles viables de développement régional du secteur irrigué.

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1. FUTURE FOOD AND WATER DEMANDS

1.1 Food Demands

Following World War II, the population of the globe more than doubled, increasing from 2.5 million in 1950 to 5.3 billion in 1990. Most of this increase took place in the poorer countries of the world where the population grew from 1.6 billion in 1950 to 4 billion in 1990.

The largest population increases will be in Asia where the annual growth rate will be 56 million from 1990-2000. Then, the population rate will decline. But, by the year 2050, it is expected that Asia's population will exceed the world population in 1990 (Yudelman, 1993).

The most important food in the developing world are cereals, which include rice, wheat, corn, millet, sorghum, rye and barley. About 52 percent of the global supply of cereals is grown in developing countries including 94 percent of the world's supply of rice, 50 percent of the global wheat supply, and 40 percent of coarse grains. Overall, cereals accounted for about 83 percent of the major food production in developing countries during 1980. Regionally, Asia is the largest producer and consumer of grain, accounting for 75 percent that is produced and consumed in developing countries. The consumption of cereals in the developing countries has risen from 170 kilograms (kg) per person per year in 1960 to 236 kg/person/year in 1990 (Yudelman, 1993).

The possibility of increasing farmers' yield depends on the present level of yields and the technologically "potential" yield. The technologically potential yield can be enhanced with research, but there are physiological limits to the process that science has not yet overcome. In fact, plant breeders are rather skeptical about achieving the type of scientific breakthroughs that launched the green revolution.

In the late 1970s, scientists believed that there was a significant amount of "untapped yield potential" in irrigated production system. Moreover, they observed that much of this could be captured by improvements in crop management in general and water management in particular. Surprisingly, by the end of the 1980s, some researchers were observing a stagnating or declining trend in the productivity of major food grains grown mainly under irrigation.

For rice, recent studies indicate that the technological yield frontier has stagnated and shown signs of long-term decline. Farm level evidence indicates that farmer yields are catching up to the yield frontier in a few countries and that further exploitation of the present yield gap is not economical. Incremental costs of achieving further yield gains exceed the incremental returns. Similar declining rice yield trends have been observed in other experiment stations in India, Thailand and Indonesia (Pingnali et. al 1990).

Yet to meet projected food demands by the year 2025, rice yields in developing countries will have to exceed average yields presently being achieved in developed countries. For other cereals, present yields in developed countries must be achieved by developing countries in 2025 (Yudelman, 1993).

1.2 Urban Water Demands

By the turn of the century, half of the world's population will be living in urban areas. There will be 21 megacities (more than 10 million people), of which 18 are located in developing countries.

The water supply situation for many cities in the developing countries has become deplorable. Many neighborhoods only receive water 1-4 hours per day. Certainly, obtaining clean water is an increasing problem for many urban areas.

In many arid countries, 80-90 percent of the available water resources are diverted for irrigated agriculture.. With time, some portions of these water supplies will have to be diverted from agricultural uses to urban uses. In many cases, surface water supplies will be diverted to groundwater recharge basins. A crude estimate is that each million of additional urban dwellers will require a water supply comparable to 10,000 ha of irrigated land. Thus, if the urban population increases by 2.5 billion people from 1990-2025, then 25 million ha of land would have to go out of production unless much higher management practices can be implemented on existing irrigated croplands.

2. SITUATION

2.1 Groundwater Development

A very large proportion of surface irrigation projects in the developing countries are large-scale public-sector projects funded by government or state revenues and managed by public-sector officials. However, recent technological changes have brought an important private-sector component into the picture. The development and diffusion of inexpensive, internal combustion engines and pumps have made it possible for individual farmers, or groups of farmers, to use small wells to exploit shallow groundwater aquifers, and to use low lift pumps for drawing water from rivers and channels to irrigate rice in the "dry season." Expansion has been most pronounced in Asia (Yudelman, 1993).

There has been a proliferation of wells owned by individuals in South Asia and by groups in China (Yudelman 1989). Private groundwater development has enabled large areas with good land and irrigation potential to be brought under production quickly, almost certainly more rapidly than would have been the case in state-controlled projects. In Thailand, there are more than 5 million small pumps used primarily to lift water from canals and rivers to use on rice paddies. The spread of private wells has been most notable in India where the number of wells increased from 459,000 units in 1968 to 3.3 million units in 1984/1985. Within India, in the state of Uttar Pradesh, privately owned tubewells increased more than tenfold from 120,000 to 1.6 million during this period. About 1.1 million of the 1.6 million tubewells are diesel-powered with the remainder using electric pump units. About half of the irrigated area is now said to be served by underground water. Much of this is in command areas, and complements the use of surface water (Yudelman 1989).

The spread of privately owned wells has increased dramatically during the past decade. Private groundwater development in places like central India and parts of Bangladesh appears to have been a great success. However, there is a significant lag in the institutional, legal and technical arrangements for managing this phenomenon in such a way as to safeguard the natural resource base, promote equity and optimize the use of water (Le Moigne et al. 1991). This is partly due to a lack of adequate information to make sound judgements about the extent to which the groundwater table is being depleted (Mohtadullah, et al. 1994).

2.2 Irrigation Development and Agricultural Productivity

There are many difficulties with statistical data for irrigated lands. However, the total estimated land under irrigation is approximately 225 million hectares (ha). Slightly more than 60 percent of this land lies in Asia, with China, India and Pakistan accounting for half of the world's irrigated cropland. During the time period 1960-90, the amount of irrigated land increased by 71 million ha, while Asia alone increased by 60 million ha according to FAO statistical data.

Between 1950 and 1982 the World Bank loaned $10 billion for irrigation development, with 90 percent of these loans being made in the 1970s. These loans averaged around 40 percent of total project costs, so World Bank support represented a total investment of $25 billion. Donor investments have declined considerably since their peak in 1979 (Yudelman, 1993).

In most countries, the potential for expanding the area under irrigation is diminishing rapidly mainly because of the escalating cost of tapping and developing new sources of water -- the easy and cheaper sources are already in use. Also, because of the decline in grain prices during the 1980s, the major donors have reduced the level of funding for irrigation development - especially for new construction.

Expanding the "effective irrigated area" by increasing cropping intensity would be an economical option for areas where further expansion in the irrigated land frontier is constrained due to financial problems, limits in water sources or supply etc. Increases in cropping intensity can be done effectively in several ways: (a) Introducing early maturing crops, thereby increasing the effective area planted to those crops per unit of time; (b) Multiple and relay cropping; and (c) Cultivating 2-3 crops per year by adopting water-saving techniques. Staggering of land preparation, planting and other cultivation methods is a common phenomenon in many irrigation systems.

A great deal of development outside the traditional mono-crop farming is necessary not only to optimize the financial and economic returns to investment made in the irrigation sector, but also to improve the living standards of the growing populations in developing countries. Recently, crop diversification has been assigned a prominent place among the avenues available for improving land and water productivity. A limited water supply condition not adequate to meet the requirements of rice during the dry season is experienced in many schemes with favorable soil conditions. Related to this is the distinct uni-modal dry season rainfall pattern which makes it possible to have a well-aerated favorable environment for irrigated crop

diversification. Water productivity, in general, can be increased under a diversified cropping pattern. Moreover, limited water available in the soil is better utilized by a mix of crops. Economic viability of such systems, therefore, may be maintained by diversification. The progress in a program of diversified cropping, however, depends on a variety of factors: (a) compatibility of the selected crop mix and land, water, climate, etc; (b) expected fluctuations of profits due to price shifts; and (c) problems associated with markets and marketing risks associated with a particular cropping pattern, farmers' resource endorsements, etc. (Mohtadullah, et al, 1994).

2.3 Trends in Sustainability

Presently, there are a number of indicators that imply that many of our irrigation systems located in developing countries are not sustainable. In other words, the agricultural productivity is stagnant and in some locations declining. Yet, there is an urgent need to increase the agricultural productivity of irrigated croplands.

One of the first obvious indicators of a lack of sustainability is declining agricultural productivity, particularly at the lower periphery of an irrigation system. Another visual indicator is soil salinity.

The strongest indicator that an irrigation system is not being sustained is a deteriorating infrastructure. The majority of the irrigation systems constructed from 1950-1990s are not being properly maintained. Often, rehabilitation is viewed as the only mechanism for correcting deferred maintenance deficiencies, which is quite similar in cost to the original investment in constructing the irrigation system.

A deteriorating infrastructure results in a declining capability for properly operating the system in a predictable, reliable and equitable manner. This, in turn, limits the management options for farmers, including crop diversification.

When groundwater levels continue to decline for more than one decade, then the indication is that the present levels of pumping are not sustainable. Also, if the salinity concentration in the pumped water continues to rise year-after-year, even gradually, the indication is the pumped discharge rates cannot be sustained.

When the domestic water supplies for cities are inadequate, both in terms of quantity and quality, with the situation worsening year-by-year, then the urban water system is not sustainable.

There are an alarming number of indicators that irrigated agriculture is facing a deteriorating situation. Many irrigation systems are not presently sustainable. This situation needs to be reversed so that irrigated agriculture can partially satisfy urban water needs while increasing agricultural productivity on existing croplands. In a very practical sense, all of this has to be achieved in the context of sustainability.

3. SYSTEM PERFORMANCE

3.1 Maintenance of Irrigation Systems

The major agricultural focus in the future for most countries in the world will be on improving management practices in order to increase crop production on existing agricultural lands. However, for irrigated agriculture, deteriorating irrigation channels and inadequate operating procedures often preclude any significant improvement. Improving the performance of an irrigation system begins with correcting maintenance deficiencies that impede good operating procedures.

The following comments are an outline of thoughts regarding how various maintenance programs impact the performance of an irrigation system. The roles of maintenance options 1, 2 and 4 are illustrated in Figure 1, with option 4 consisting of two combined maintenance programs.

1. Normal or Routine Maintenance;
2. Preventive Maintenance;
3. Rehabilitation; and
4. Essential Structural Maintenance (ESM) and "Catch-up" Deferred Maintenance.

The maintenance terminology in Figure 1 explains the difference between options (1) and (2). The usual emphasis upon using available resources to correct major maintenance deficiencies appears to be very logical; however, this is much more expensive than training the field staff in order to develop "maintenance eyes" wherein minor problems are mentally perceived as to how they grow in time to become major maintenance problems and that it is much more economical to correct maintenance problems when they are only minor. There is a need to document the difference in cost between these two options.

Option 3 (Rehabilitation), which is not really a maintenance program but rather a construction program, is by far the most expensive of all options. Consequently, this option leads to an increased national debt burden. Usually, a rehabilitation program is done by the Construction Division of an Irrigation Agency, rather than the field O&M staff, which means that the field staff do not "learn" from this program. Also, the O&M field staff inherit an improved system, but still only have the same resources for annual maintenance as prior to rehabilitation. There is a need to identify the necessary components of a rehabilitation program that will sustain the system in good condition.

The combination of Essential Structural Maintenance (ESM) and "Catch-up" Maintenance (Option 4) were developed as an alternative to rehabilitation. The expected costs are about one-third of rehabilitation. Field experience in Sri Lanka and Thailand verifies this cost. In fact, ESM is considered the minimum level of investment that should be made in order to improve water deliveries (Skogerboe, 1990).

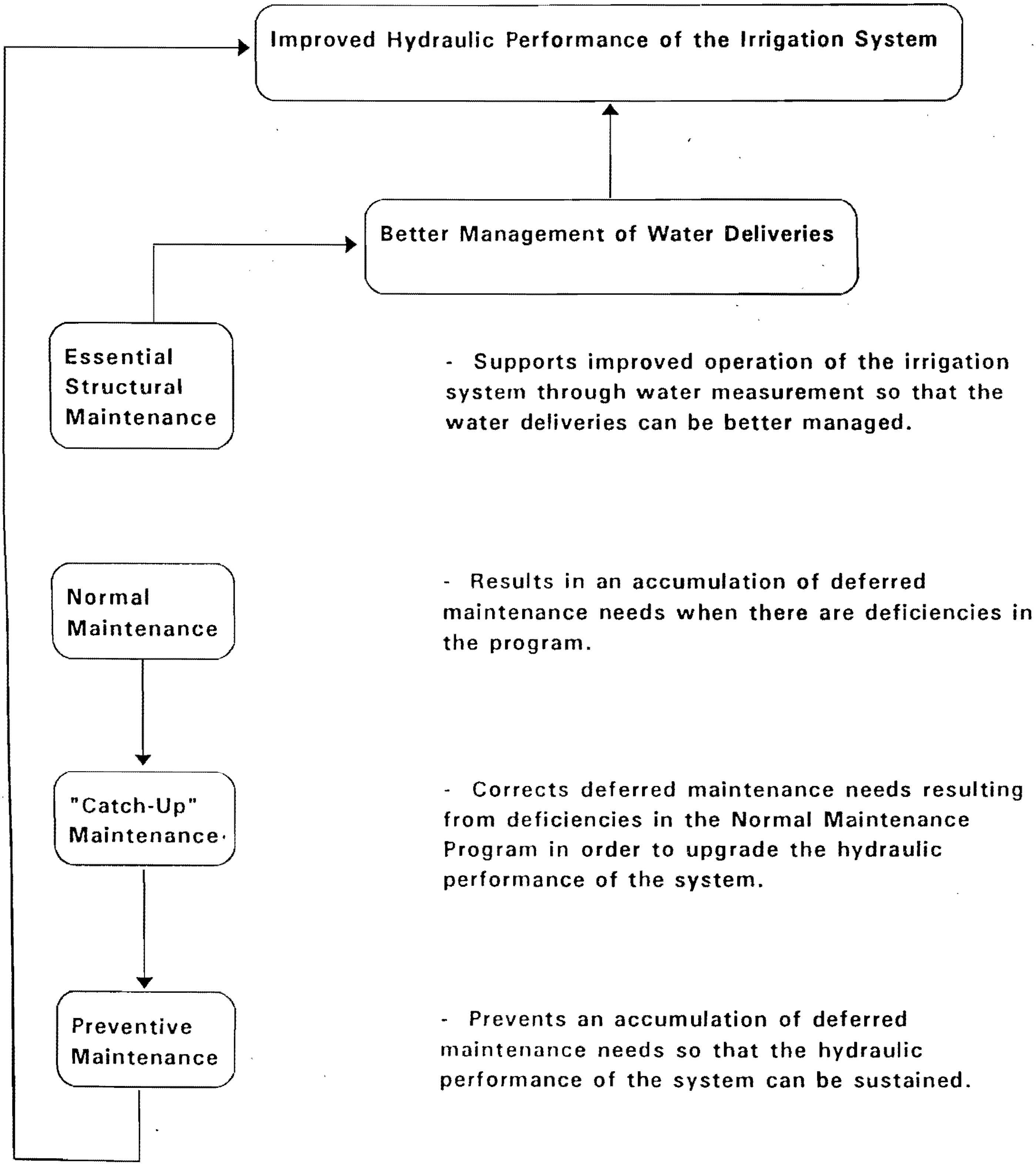

Figure 1. Role of maintenance programs for improving the hydraulic performance of an irrigation system.

3.2 Impact of Maintenance Options on Irrigation System Operations

There are three major topic areas to consider: (1) inadequate maintenance; (2) inadequate operations practices; and (3) inadequate organizational management. The following is not an exhaustive listing of concerns in each topic area, but does illustrate the issues.

A number of inadequate maintenance practices lead to increased channel losses. Other deficiencies lead to reduced channel capacity. Often, the channel capacity is only 80 percent, or less, than the design discharge capacity.

Inadequate operations practices result, first of all, from not knowing the discharge ratings at flow control structures, of using design equations which are usually in error by 10-30 percent. Secondly, the water losses are not known; the change in water loss with operating water level should be known for each reach in the system. There is a lack of monitoring, so that the discrepancy between planned and actual water deliveries is unknown. Inadequate monitoring also results in a lack of knowledge about system performance -- is hydraulic performance improving each succeeding year, static, or declining? The final result is inequitable water deliveries to each of the outlets (turnouts) serving a tertiary subsystem.

Deficiencies in organizational management result, most of all, from an emphasis on administrative paperwork management rather than technical matters of maintenance, operations, and water management. An almost universal problem in developing countries is the lack of field experience -- more field training and field experiences are required. There is a lack of communications between project management, field staff, and farmers. There is also a lack of accountability. All of these deficiencies lead to a major credibility problem by project field staff with (1) farmers; and (2) the central headquarters of the irrigation agency.

3.3 Impact of Operation Practices on System Performance

To truly evaluate the impact of the various maintenance options, it is necessary to not only relate the impact of each option on operations practices, but also to relate the impact of operation practices on many larger issues; agricultural productivity; economic distribution; social organization; sustainability; and urban water transfers. Only general comments follow. The details need to be developed and specified on how to relate operations practices with each of these major issues for each irrigation system.

3.3.1 Agricultural productivity

The vast majority of irrigation systems in developing countries provide water supplies to surface irrigated fields -- most commonly basin irrigation. The hydraulics of surface irrigation, combined with hundreds of field evaluations, discloses that irrigation application efficiencies will be low if a variable discharge rate is inflowing onto the field.

Unreliable and erratic water deliveries also has a highly significant impact on the crops a farmer will plant and also their resulting yield.

For countries seeking crop diversification (e.g., the majority of countries in Asia), inadequate operations practices greatly discourages farmers and agri-business from investing in higher cash value crops. Thus, crop diversification can only be successful in irrigation systems than can deliver equitable, reliable and predictable water supplies.

Agricultural development programs are unknowingly doomed to dismal results because of inadequate operations practices. Yet, if an irrigation system is being properly operated, then investments in the tertiary subsystems, agricultural production, marketing and food processing have a very high payoff.

3.3.2 Economic distribution

When walking around inside an irrigation system, one of the most appalling features is the tremendous disparity in family incomes -- from poverty to being fairly wealthy. Numerous examples can be cited, from abandoned lands, one crop every other year, no water when needed, and flooded land when there is a plentiful rainfall. Sometimes, these are indicators of an inadequate water supply, but more frequently they are indicators of gross mismanagement of the available water supplies, and the distribution of socio-economic power among the farmer families.

3.3.3 Social organization

There is a growing emphasis on turning over agency-managed irrigation systems to farmers. There are many good reasons for this movement. But, on many systems operated by irrigation agencies, the farmers are already in control and the irrigation engineers have lost control for a variety of very understandable reasons. The problem is that anarchy exists on these systems -- only some groups of farmers are benefiting while others are suffering. A major reason for this dilemma is inadequate operating practices by the irrigation agency and political interference.

3.3.4 Sustainability

Sustainability is an important concept to be applied in irrigated agriculture. Answering the question of sustainability requires that the operating procedures be specified as a long-term, or time dependent, objective. Because of the "site specific" nature of irrigated agriculture, the hydraulic performance criteria would be different for each irrigation system in order to assure sustainability.

3.3.5 Urban water transfers

In the early stages of development within a river basin, most of the emphasis is on hardware solutions. As resources use continues to rise, an increasing emphasis has to be placed upon software solutions.

In many countries, irrigation is the greatest consumer of water. In such cases, if urban population growth is high, and new sources of water supply are extremely difficult to obtain,

then water transfers from irrigated agriculture to urban areas may be highly desirable. However, if an irrigation system is being poorly operated, thereby limiting crop production, then diverting a portion of the irrigation water supply to an urban area will significantly reduce crop production. In contrast, a highly productive irrigation system could more readily adapt to a slightly reduced water supply, and at the same time, further increase agricultural productivity.

3.4 Institutional Influences on System Performance

The institutional framework for irrigation in a country characterizes how irrigation system performance is generally perceived in that country. In their functioning, the institutions tend to portray the value that is attached to performance and its assessment, and the way in which performance is assessed and how the results are used. They also help to identify the different roles played by different individuals and groups, and specify the underlying rules of the game. In many developing countries, particularly in South Asia, irrigation institutions are found to be rigid, embedded in deep-rooted "irrigation culture", and therefore less responsive to performance assessment and related needs for change (Bandaragoda 1993b). Thus, most of the problems of maintenance and operations mentioned in the foregoing section are directly linked with the institutional framework.

Legal Framework, Governance, Organizations, and Finance can be identified as the four main aspects, which form a basis for analyzing and understanding the range of variations of irrigation institutions that can be seen in different contexts (Merrey 1993). Outlined below are some features of each of the main aspects, in the order of importance attached to them in most developing countries.

3.4.1 Organizations

Organizational arrangements for irrigation can be seen in three categories:

* Organizations for water delivery and related services, usually the irrigation-related public agencies, such as the Irrigation and Agriculture Departments, which play a dominant role in many aspects of irrigation in developing countries;

* Agency-farmer interface, which is still a fairly weak link in the institutional framework; and

* Organizations for water use and related functions, such as water users associations (WUAs) which have been increasingly emphasized in recent times.

The major issue impacting performance is the sharing of power and authority for irrigation management decisions among these three categories of organizational mechanisms. Often, the dominance of public irrigation organizations derived from the deep-rooted administrative culture in many developing countries has tended to ignore the important contribution that the users themselves can make in improving performance. Apart from the dominance of this sector, the lack of coordination among the various agencies in interacting with farmers compounds the difficulties in achieving adequate benefits from the water delivery subsystem. The resultant

complacency on the part of both agency staff and the farmers, and their respective isolation from one another, have not been helpful in creating effective user organizations. This situation of general neglect affects most seriously the desired equity in water distribution and use, and particularly under conditions of water shortage, which is most often the case, inequity affects adversely on overall performance.

3.4.2 Legal System and Governance

The presence of "soft state" conditions in many developing countries have made whatever the legal framework available for supporting irrigation management totally ineffective, and almost operational as a major impediment to performance. Water thefts are rampant, pressure from the influentials and the related rent-seeking behavior by the field level officials accentuates inequity, and long procedures in arbitration mechanisms discourage the aggrieved parties from seeking remedies. Informal rules have superseded the formal rules (Bandaragoda 1992). Although the traditional legal base has tried to stabilize a system of water rights, the informal behavior has disturbed it considerably, and the emerging market pressure is making it redundant. A review of the legal framework, including the laws and procedures governing the various irrigation organizations, is due in many developing countries, to ensure that it promotes improved performance.

Governance, which basically determines the allocation of power and authority, explains who is responsible for what functions of irrigated agriculture and within what bounds. The overall nature of governance in a country plays a significant role in defining governance for irrigated agriculture. The will to share power and responsibility among various agencies, and between agencies and users, is a direct derivative of the prevailing form of governance. A shift from the remote centralized authority system to a secondary and tertiary subsystem is considered more advantageous to the users and having a greater potential for improved performance.

3.4.3 Resource Mobilization and Allocation

This is yet another important aspect which primarily affects the institutional performance, and through it, the overall performance of irrigation. Adequacy and timeliness of the availability of financial and manpower resources greatly influences the organizational behavior, individual motivation and the interaction processes. These behavioral aspects in turn affect performance, irrespective of other managerial influences. Similarly, the payoff to many delivery functions fashions the willingness of beneficiaries to pay even part of the cost of irrigation services. The effect of this vicious circle pervades the irrigation scene in developing countries.

4. IRRIGATION "LEARNING"

4.1 Irrigation Maintenance and Operation Learning Process

An important **strategy** for increasing the agricultural productivity of existing irrigation systems is, first of all, to evaluate the maintenance deficiencies on any particular irrigation system and then **correct all maintenance deficiencies** that interfere with the proper operation of the irrigation channels. Secondly, **improved operations practices should be developed** that will provide reliable, predictable and equitable water deliveries to each outlet (turnout) structure serving a tertiary subsystem. Thirdly, when operations practices have been improved, then **technical assistance should be provided to the farmers** so they can improve their water management practices in order to increase crop production.

STRATEGY
for improving
Existing Irrigation Systems

1. **Correct Maintenance deficiencies;**
2. **Improve operations** practices to provide more reliable, predictable and equitable water deliveries to outlets serving farmers groups;
3. **Provide technical assistance to farmers** for enhancing tertiary subsystem management;
4. **Sustain a Preventive Maintenance Program** that avoids the need for Rehabilitation; and
5. **Continually improve operations** practices to support an increasingly more diverse, productive and sustainable agricultural system.

The Irrigation Maintenance and Operations (M&O) Learning Process has been developed (Skogerboe, 1990) to provide guidelines that will : (a) **identify problems** which commonly prevent irrigation systems from delivering reliable and equitable supplies; (b) **develop solutions** which on implementation would be able to treat the causes of the problems, rather than just the symptoms; and (c) **provide field experience** and insights for further improvements in the irrigation system. This process is meant to develop appreciation and create awareness among technical staff of the irrigation agency, as well as farmers and senior officials, by creating visible **success stories** at those irrigation systems selected for improvement.

Recognizing the "site specific" nature of irrigated agriculture, where **each project area is uniquely different**, an effective **approach must be process oriented**, rather than an approach which emphasizes technology alone, or a "prescriptive" approach that lists step-by-step procedures that are to be used on every irrigation project. Although a "prescription" is usually preferred by most irrigation officials, the disadvantages are: (a) the procedures will lead to less than optimal results for most projects; and (b) project field personnel do not "learn" how to accommodate the unique characteristics within their project area in order to improve the performance of the system. Instead, **a process** (or a series of processes) **is required** that is capable of being adapted to each "site specific" situation in order **to be transferable.**

The maintenance and operations "learning process" provides one technological approach for effectively sustaining an irrigation network over a long time period. This process emphasizes:

(a) maintaining rather than rehabilitation;
(b) documenting maintenance needs to improve financial management and accountability;
(c) using existing flow control structures in irrigation channels for water measurement;
(d) developing more detailed physical knowledge about what is occurring within the system;
(e) increasing sensitivity about operating the system to meet the needs of farmers; and
(f) documenting the needs and costs for irrigation system improvements.

In discussing maintenance and operations (M&O) issues, it is useful to subdivide the water delivery subsystem into the main canal and branch canal (principal canal subsystem), the secondary canal subsystem consisting of distributaries and minors, and the tertiary subsystem which is a watercourse. The tertiary subsystem is the land served by the last flow control structure (outlet) along the secondary subsystem. An irrigation project consists of a principal and secondary subsystem channel network (called main subsystem) that serves many outlets.

This process is focused upon the water delivery subsystem, but the same principles would apply to the water removal subsystem (surface and subsurface drainage channel network). Most likely, the farmers would be responsible for maintaining the drainage channels in the tertiary subsystems, while the appropriate government agency would maintain the main drains and the branch drains flowing into each main drain. Generally, the maintenance of drainage channels is quite neglected because few funds are provided for this purpose.

4.2 Turnover of Irrigation Systems to Farmers

In recent years, more and more publications on irrigated agriculture are stressing that the most important activities in the near future should be "main system management" (e.g., Chambers, 1988 and Walker, 1990) and "maintenance" (e.g., World Bank 1991). In fact, the two activities go hand-in-hand. Maintenance is a support activity to facilitate operating the irrigation channels, or main system management.

This increased emphasis by donors and other organizations has resulted from a recognition that, in general, irrigation infrastructure is deteriorating, particularly in those cases where irrigation projects are managed by government agencies. In viewing the situation world-wide, one obvious conclusion is that the best-operated irrigation systems are managed by farmers, not government agencies. This is not only true for small irrigation systems, but for large systems as well.

An irrigation project is usually typified under three types of management: (a) agency-managed irrigation system (AMIS); (2) jointly managed irrigation system (JMIS); and (3) farmer-managed irrigation system (FMIS) (Manor, Patamatamkul and Olin, 1990). The focus herein is to move from AMIS to FMIS using JMIS as the driving mechanism. For the Indus Basin Irrigation System, the authors perception would be that a process is required that gives farmers control of the secondary and tertiary subsystems.

A learning process has been developed wherein both farmers and agency field staff develop field experience together with improved M&O practices. More importantly, this process for creating and then strengthening farmers water users organizations (WUOs). At same time, the field capability of the agency staff will be enhanced. For the sake of brev the details of this process are not described. The interested reader can consult the refere (Skogerboe, Poudyal and Shrestha, 1993) to obtain more details.

The successful implementation of this process is expected to result in turnover to farmers (FMIS) after 2-5 years. Limited success may result in continued joint management decades. Failure to develop credibility between farmers and agency field staff wl implementing this process will result in the project being farmer-managed, but under anarc rather than having effective farmers organizations that can equitably distribute the irrigat water supplies and sustain the physical infrastructure.

4.3 Improving Irrigation Water Management on Farms

Once the main system is being properly managed, then it becomes highly beneficial focus on the tertiary subsystems, including the croplands. This is much more complex than main system, not only because of the numerous government and private organizations involv but also the complex physical and social phenomena. There does exist an interdisciplin approach that is client-oriented for improving water management practices and agricultu productivity in tertiary command areas (Skogerboe, et al., 1982)

4.4 Irrigation Salinity Management

An important measure of sustainability for many irrigation systems is salinity. I example, the Imperial Irrigation District (160,000 ha) monitors the annual salt balance for entire system as a highly important performance parameter that indicates whether salts in the s profile are accumulating or being leached. Again, there is a process available (Skogerb Walker and Evans, 1979) that can be used as a guide in developing cost-effective solutions managing salinity on irrigated croplands.

5. SUMMARY AND CONCLUSIONS

For irrigated agriculture, the question of sustainability is one of resource manageme At the same time, irrigated agriculture is "site specific", so that resource management practi must be appropriate to the physical and institutional environment.

To increase crop yields and cropping intensities on existing irrigation systems requi continual improvements in water management practices to meet future food deman Maintaining the physical environment for a productive agricultural system also requires contin improvements in agronomic (including irrigation) practices.

To continue pumping groundwater on a sustainable basis requires the proper combinat of groundwater and irrigation practices that will also have to be continually improved over tir

Irrigation water supplies can be partially diverted to urban areas, without decreasing agricultural productivity, only if water management practices are further improved. In fact, a highly productive and sustainable irrigation system should be capable of increasing crop production with reduced water supplies, provided the management practices are properly adjusted to the decreased water supply.

A major question being addressed in many countries is the turnover of operations and maintenance activities for irrigation projects from public agencies to water users organizations. Turnover processes are being experimentally implemented in a number of Asian, Latin American and African countries. Many recent studies by IIMI have investigated farmer-managed irrigation systems. (Manor, et. al, 1990; Yoder and Thurston, 1990). Serious discussions are underway in Pakistan regarding privatization of the world's largest irrigation system, but of course, there is considerable resistance.

A number of organizations have made important strides in developing improved procedures for computer operation of irrigation systems. The implementation of this technology is now gaining momentum. Research has clearly shown that perturbations of water levels and discharges in canals are magnified as these flows move into the lower secondary and tertiary channels.

Likewise, research on surface irrigation of croplands shows that fluctuating discharge rates applied to croplands results in low application efficiencies. This, in turn, limits crop yields and reduces crop quality, thereby lowering profits.

In many developing countries, agricultural policies benefit urban consumers at a significant cost to rural farm families. Often, these policies are a definite deterrent to increasing agricultural productivity.

For irrigated agriculture, there is a formidable task ahead in the next 10-30 years. Rapidly increasing populations, the necessity for improved diets, and limited potential for expanding the amount of land that can be irrigated present a major challenge. But, deteriorating physical infrastructure, increasing soil salinization, tremendous inequities in water distribution, stagnant crop yields, and declining sustainability in many locations are symptomatic of major obstacles that must be overcome in meeting the challenge. Certainly, improved technologies are needed, but the greatest impediments to achieving the required agricultural outputs in the context of sustainability are institutional. In fact, institutional measures must lead the way in continually sustaining an increasingly more productive agricultural system, with technology providing the necessary support that facilitates the success of such institutional measures.

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