



A study on improvement needs for the soil water balance

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ARTICLE INFO	ABSTRACT
<p>Original Review Article Received on April 12, 2020 Revised on April 24, 2020 Accepted on May 14, 2020 Published on May 25, 2020</p> <p>Article Author Attia El Gayar</p> <p>Corresponding Author Email attiaelgayar@yahoo.com</p>	<p>One critical problem confronting mankind today is how to manage the intensifying competition for water among expanding urban centres, traditional agricultural activities and in-stream water uses dictated by environmental concerns based solely on the soil water balance. In the agricultural sector, the prospects of increasing the gross cultivated area are limited by the dwindling number of economically attractive sites for large-scale irrigation and drainage systems whose correct evaluation depends on the understanding of groundwater movement in three dimensions. The failure of present systems, and inability of sustainable extraction from surface and groundwater sources may be attributed, essentially, to poor planning, design, management and development, as not much is known about groundwater flow systems. Each flow system has different chemical quality, path of travel, recharge area, as well as water age. To take full advantage of investment in agriculture, a major effort is required to modernize irrigation and drainage systems and to further develop appropriate management strategies compatible with financial and socio-economic trends, considering the functioning of groundwater components in the environment. This calls for a holistic approach to irrigation, drainage management, and monitoring if the aim is to increase food production, conserve water, prevent soil salinization and water logging, and to protect the environment. Sustainable development should be based on a full understanding of the relationship between the used water source and the environment. To tackle this challenge, there is a need to focus on the following issues: affordability with respect to the application of new technologies; procedures for integrated planning and management of irrigation and drainage systems; analysis to identify causes and effects constraining irrigation and drainage system performance; evapotranspiration and related calculation methods; estimation of crop water requirements; technologies for the design, construction, and modernization of irrigation and drainage systems; strategies to improve irrigation and drainage system efficiency; environmental impacts of irrigation and drainage systems and suitable measures for creating and maintaining sustainability. Institutional strengthening, proper financial assessment, capacity building, training and education actions are also required to achieve a successful on the soil water balance.</p>
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To take full advantage of investments in agriculture, a major effort is required to modernize irrigation and drainage systems and to further develop appropriate management strategies compatible with the financial and socio-economic trends, and the environment. This calls for a holistic approach to irrigation and drainage management and monitoring so as to increase food production, conserve water, prevent soil salinization and water logging, and to protect the environment (Malek-Mohammadi, 1998, Dudley, 1999). All this requires, among others, enhanced research and a variety of

tools such as water control and regulation equipment, remote sensing, geographic information systems, decision support systems and models, as well as field survey and evaluation techniques.

Trends in Irrigation and Drainage

Basis for the water management requirements is the world's population, its growth and its standard of living. With respect to water management related to agricultural production there are broadly speaking three agro-climatologic zones,

being: temperate humid zone, arid and semi-arid zone and humid tropical zone.

In addition, in principle, four types of cultivation practices may be distinguished, being:

- Rain fed cultivation, without or with a drainage system;
- Irrigated cultivation, without or with a drainage system.

Dependent on the local conditions different types of water management with different levels of service will be appropriate (Schultz, 1993). At about 1,100 million ha agricultural exploitation takes place without a water management system. However, in a certain part of these areas methods like water harvesting or soil treatment may be applied. From these areas 45% of crop output is being obtained. Presently irrigation covers more than 270 million ha and is responsible for 40% of crop output. It uses about 70% of waters withdrawn from global river systems. Drainage of rainfed crops covers about 130 million ha and contributes to about 15% of crop output. In about 60 million ha of the irrigated lands there is a drainage system as well (Smedema, 1995 and 2000).

Based on the forecasts for population growth and the improvement in the standard of living it is expected that food production will have to be doubled in the next 25 years. In addition it is expected that 90% of the increase in food production will have to come from existing cultivated land and only 10% from new land reclamations, either in the highlands, or in the lowlands. There is no way that the cultivated area without a water management system can contribute significantly to the required increase in food production. Due to this the share of irrigated and drained areas in food production will have to increase.

This can be either achieved by installing irrigation, or drainage systems in the areas without a system, improvement, or modernisation of existing irrigation and drainage systems, installation of irrigation systems in the rainfed drained areas, or installation of drainage systems in irrigated areas. A rough estimate may be that over the next 25 years this may result in a shift to the contribution to the total food production in the direction of 30% for the areas without a water management system 50% for the areas with an irrigation system and 20% for the rainfed areas with a drainage system. It has to be

realised that these percentages refer to two times the present day food production.

In addition it has to be realised that it will be extremely difficult to achieve this in an environmentally sustainable way, especially in the emerging developing countries (Biswas, 1996, Frederick, 1996).

Sustainable development can be viewed as a process of change in which the exploitation of resources, the direction of investments, the orientation of technological innovation and adaptation, along with institutional changes, are all in harmony and enhance both the current and future potential, to meet growing human needs and aspirations (WCED, 1987). Concerning agricultural water management, most of the world's irrigated land and rainfed land with drainage facilities were developed on a step-by-step basis over the centuries. In many of the systems structures have aged or are deteriorating. Added to this, the systems have to withstand the pressures of changing needs, demands and social and economic evolution.

Consequently, the infrastructure in most irrigated and drained areas needs to be renewed or even replaced and thus redesigned and rebuilt, in order to achieve improved sustainable production. This process depends on a number of common and well-co-ordinated factors, such as new and advanced technology, environmental protection, institutional strengthening, economic and financial assessment, research thrust and human resource development. Most of these factors are well known and linked to uncertainties associated with climate change, world market prices and international trade. These uncertainties call for continued attention and suitable action on many fronts, if productivity and flexibility in agricultural systems is to be improved.

In this context the increased value of crops per area and the intensified land use will play an important role. In addition the effects of climate change may play an important role in certain regions (Frederick *et al.*, 1997, Ragab *et al.*, 2000). Availability of reliable hydro-climatic data is an essential prerequisite for the rational planning, design and management of water resources. Irrigation and drainage systems were designed for a long life, on the assumption that climatic conditions would not change in the future. This will not be so in the years to come, due to global warming and the greenhouse effect.

Therefore, water management system designers and managers need to systematically re-examine engineering design criteria, operating rules, contingency plans and water allocation policies. Demand management and institutional adaptation are essential components for enhancing system flexibility to meet the higher standards of service provision. More emphasis should be placed on demand management rather than on construction of new facilities.

All the above factors and constraints compel decision makers to review the strengths and weaknesses of current trends in irrigation and drainage and rethink technology, institutional and financial patterns, research thrust and manpower policy so that service levels and system efficiency can be improved in a sustainable manner. To develop this process in a well-planned and controlled way the following aspects need to be adequately addressed (De Wrachien, 2001):

- A-Technology
- B-Institutional and financial aspects
- C-Research and development
- D-Human resources and networking

A-Technology

Technology in irrigation and drainage development is concerned with the planning, design and control of the systems, including water conveyance, regulation structures, water quality and environmental protection measures. It is also concerned with modernization procedures and methods for conjunctive use of surface and groundwater to minimize water use and reduce deep percolation. Some basic aspects, important in the process of technological innovation and improvement, are:

- Planning and design
- Management, operation and maintenance
- Performance assessment
- Constraints and environmental impacts
- Modernization
- Integrated use of surface and subsurface water resources.

Planning and Design

The planning and design of irrigation and drainage systems should be viewed as an aspect of agricultural development concerning the private

sector as well as the national economy. So, particular attention should be paid to:

- The importance of water for agricultural production in relation to national water use
- Historical water use practices
- Effect on the local hydrological environment;
- Sustainable management of water quality and quantity.

In this context, the process of determination of design parameters, selection of systems and materials, construction methods, operation and maintenance aspects has to proceed in a balanced way, in order to optimise designs and to take into account the interactions among land use, agricultural practices and the layout and characteristics of irrigation and drainage networks (Storsbergen, 1993).

The choice of an irrigation or drainage technique will depend on the environmental conditions. For irrigation, options include basin, furrow, sprinkler, drip and subsurface methods. For drainage systems the available methods include deep and shallow tube wells, skimming wells, wide-spaced and narrow-spaced drain pipes, deep and shallow ditches, surface drainage or mole drains. Planners and designers have to incorporate sufficient flexibility into the networks to be able to cope with changes in the objectives of the systems. These may be due to alteration of cropping patterns, agrarian structures, urbanization, infrastructure, agricultural practices, mechanization, hydrological regime, water management and water use trends.

Research on the planning and design of irrigation and drainage systems has to deal with different aspects such as: design criteria and design methods, materials, construction, maintenance, control and inspection equipment, institutional and financial aspects of system construction, operation and maintenance. Because of the increasing scarcity of usable water resources, special attention should be paid to the control (reuse and disposal) of agricultural drainage water. The objective of this is to optimise the efficiency of available land and water resources use with the ultimate goal of enhancing crop yield and production. For a well planned and controlled irrigation and drainage system, the following aspects need to be taken into account during the design stage:

- Data on climate, cropping pattern, stream flow, surface and subsurface water regime, water

demand for agricultural, industrial, municipal and environmental purposes

- Existing facilities (dams, canal systems and associated structures)
- Design parameters for irrigation and drainage works and associated structures, with special emphasis on how to secure and control the required water supplies
- Future operation, maintenance and management procedures including monitoring, financial and administrative facilities.

Standardization of design procedures is recommended to allow for possible decentralization of the design process. This will facilitate construction supervision and establish the basis for more rational and sustainable irrigation and drainage systems, with consequent benefits for their operation and maintenance. Design standards should be simple and precise, so as to provide designers with clear choices as to type of structures to be used and procedures to be followed.

Management, Operation and Maintenance

Good management, efficient operation and well-executed maintenance of irrigation and drainage systems are basic requisites for improving agricultural water management. They enhance both performance and crop yields, and ensure sustained production. Unfortunately, several systems are poorly managed, and not properly operated and maintained mainly because of insufficient commitment and finances. While, it is clear that adequate financing is essential, experience has shown that weaknesses in institutional, technical and managerial aspects of an irrigation and drainage organization and inadequate stakeholder involvement are also important factors that can impair system performance.

To enhance system performance and assure the ongoing integrity of its facilities good management skills are required to effectively coordinate the physical, human and financial resources involved in the system. Moreover, operation and maintenance plans are needed to establish strategies for achieving the objectives. The plans will have to consist of a permanent set of documents and instructions, work programs and schedules, updated when changes are made, that form a complete statement for reference and guidance at every level within the organization managing the systems.

Such plans would have to be the outcome of an integrated planning and management process. The process provides for a top-down approach to priority/direction setting and a bottom-up approach to devising detailed strategies and activities. Therefore, the plans can be viewed as the result of an iterative process involving the following steps:

- Identification of those activities most significantly affecting the system's overall performance
- Diagnostic analysis and identification of options for performance improvement
- Development and implementation of programs
- Monitoring and evaluating processes against agreed performance criteria
- Review of plans and programs.

The need for modernization measures normally emerges from the analysis of actual and expected performance. With respect to this it is of importance to realise that maintenance of irrigation systems differs fundamentally from that of drainage systems. Maintenance of irrigation networks should be carried out prior to the commencement of and/or during the irrigation season. The irrigation water is supplied in more or less known quantities, whereas without maintenance, the crops will not receive adequate water supply. Maintenance of drainage systems is of a more preventive nature. It should be conducted before a certain extent, unknown wet period, during which the drains have to fulfil their function. The amount of drainage water to be stored and transported may vary considerably, and the damage resulting from insufficient drainage may occur long after the wet period.

The purpose of maintenance is either to eliminate the cause of poor irrigation or drainage system performance or to prevent this from happening. In the first case proper monitoring is required, in the latter a schedule is needed, indicating the maintenance activities and their planning. On the whole, proper maintenance is critical to the success of irrigation and drainage systems, and to ensure that the design and operational objectives set by designers, planners, investors and farmers are achieved. It is also recommended that cost effective maintenance programs be developed and implemented through research and field and economic studies. In addition, operation and maintenance programs should envisage farmer and stakeholder participation to be truly effective.

Performance Assessment

System performance can be defined as the degree to which the system's products and services respond to the needs of their stakeholders, and the efficiency with which the system uses the resources at its disposal (Rao, 1993, Bos, 1994, Vlotman and Dayem, 1996). The aim of performance assessment is to select a small number of powerful, easily observable indicators that allow reliable conclusions to be drawn. The performance assessment should be a regular, short duration process for investigating suspected critical shortfalls in performance. Organizational requirements comprise some permanent, low intensity monitoring and evaluation procedures that could be supplemented by full-scale performance assessment investigations whenever major performance problems occur.

The organizations responsible for irrigation and drainage systems can be very helpful in providing information about system performance, granted they have a well-established monitoring and evaluation program and an efficient Management Information System. With respect to this it is also useful to clarify who are the actors in the field of agricultural water management. Responsible are government, irrigation and drainage agencies and farmers. This implies that in order to achieve sustainable solutions these three parties have to agree on their role and share in water management in a region. All others contribute. They are needed and have a function for various reasons, but they are not responsible. In assessing the performance of irrigation and drainage systems this implies that the following issues should be taken into account:

- Irrigation and drainage are human interventions in which the government, a service provider (the Agency) and generally the farmers are the principle actors
- Water is used (delivered and intercepted) to improve crop growth
- A level of service has been agreed between the service provider and its clients
- The service provider and its clients need to use the resources with some target level of efficiency.

Performance assessment is an increasingly relevant concept in present-day irrigation and drainage systems. This is because the gradual deterioration of a significant part of the large-scale systems developed in the second half of the 20th century is starting to become apparent.

Therefore, it is necessary to evaluate the performance of these systems before their modernization. To this end some performance indicators have been proposed for:

- Carrying out a diagnostic analysis
- Determine whether irrigation and/or drainage can be viable
- Comparing actual performance with established design criteria
- Determining whether the system requires modernization measures or simply extensive maintenance
- Identifying the required upgrading or restoration to overcome current deficiencies
- Selecting among alternatives those actions that are economically justifiable and preparing a priority list of potential modernization measures.

Performance indicators are measurable variables that describe the condition of a system and its changes over time and space. As mentioned, they enable the functioning of the system to be assessed against an agreed set of criteria. Ranges of indicator values can be established to allow the user to identify whether acceptable conditions are being achieved. Such indicators should:

- Provide important information on system functioning
- Relate to accepted standards
- Have a solid scientific base
- Be expressible in a quantitative form
- Have a high diagnostic value
- Hold a high discriminating value
- Be measurable easily and cost effectively.

The indicators should enable the analyses of the following system characteristics:

- Reliability
- Conveyance efficiency
- Adequacy
- Equity of water distribution
- Field application efficiency
- Environmental sustainability.

Constraints and Environmental Impacts

The contribution expected from the irrigation and drainage sector towards improving agricultural productivity cannot be achieved if constraints in irrigation and drainage systems are not adequately addressed.

In several cases technological problems and their adverse impacts on the environment are increasing because solutions have not been found or proven to be effective, or because maintenance has been neglected and modernization deferred. Moreover, modification of the hydrological ecosystems by irrigation and drainage works may have resulted in environmental changes commonly leading not only to reduction in water availability, water logging, salinization hazards and the spread of aquatic weeds, but also to problems affecting the health of the local population. In this regard, the most important issues that demand due attention are:

- Shortage of water supply at the source
- Poor canal regulation
- Poor operation and maintenance
- Water logging and salinity
- Water-related diseases and human health.

Preventive planning, suitable design measures and post-construction control programs can do much to mitigate or solve the above problems.

In addition to the disadvantages listed above, which are directly related to water, there are a number of other constraints. They include inadequate supplies of farm inputs, poor infrastructure, poor marketing facilities, price disincentives and other factors. Also the global trend of declining agricultural and other commodity prices during the past years creates a serious constraint. More directly related to the irrigation and drainage facilities themselves are the problems of cost of development and economic viability. As irrigation and drainage are extending into marginal areas, costs often rise to levels that prevent high returns on capital.

All these constraints present a major challenge to the sustainable development of water management for agriculture and require the combined effort of both individuals and communities. To face this challenge an integrated approach to irrigation and drainage is needed, aimed at increasing food production, water conservation, preventing water logging, soil salinization and diseases, and at protecting the environment and ecosystems.

Modernization

When serious deficiencies in system performance arise, that cannot be overcome by

simple changes in management practices, some modernization measures are called for (Price, 1999). Modernization entails increasing the original irrigation and drainage network's capacity. Modernization is often required to upgrade ageing systems. In other situations changes in land utilization, water availability or economic value of crops require the system to be modified. Inadequate maintenance is frequently the primary reason for modernization of irrigation and drainage systems to support agricultural production to sustainable levels.

It is estimated that between 50 and 70% of traditional irrigation and drainage systems worldwide are in need for some degree of modernization. Due to the dwindling number of economically attractive sites for new large-scale irrigation and drainage systems, the current tendency of decision makers is to increase resources allocated to modernization of existing systems instead of constructing new systems. Most surface irrigation systems were designed to provide almost constant rates of flow for prolonged periods of time and, therefore, have few control structures in the canal networks.

As a consequence, there is little regulation of water delivery to suit crop requirements. Moreover, in areas where there is a pressing need for diversification, existing systems cannot meet the demand for flexibility. There is a need to introduce more effective control structures within canal networks, to automate control, adopting modern information systems and to move towards more efficient operating practices. In this context, improved regulation of water delivery not only has the direct advantage of increasing crop yields, but also helps to control water logging and salinity.

Other reasons for improving the technical quality of canal networks are: reduction of seepage losses and sedimentation, control of disease vectors and weed growth. Effective research on these topics is also required for maintaining equity among farmers, particularly for managing demands during periods of water scarcity. The concept of modernization is also relevant to new systems. Some of the new technologies are particularly suitable for problem soils where traditional irrigation systems may not be feasible. Therefore, they offer the opportunity of expanding into marginal land and increasing the cultivable area.

Most modern irrigation methods allow injection of fertilizers into the irrigation water, thus economizing fertilizer use and reducing soil and groundwater pollution. Research is needed in this field to adapt such methods to specific soil, topographic, ecologic and social conditions in order to ensure that they are cost effective and sustainable. As for drainage systems, modernization measures should envisage new criteria for leaching of salts and pollutants, like pesticides and heavy metals. These criteria should achieve the right balance between agricultural production requirements and acceptable environmental impacts. On the whole the improvement and modernization of irrigation and drainage systems is a complex process. All technical solutions need to be thoroughly researched and field tested at prototype scale. It is the complexity of the problem and the lack of comprehensive research and development resources that have largely hindered technical progress in this area up to now.

Integrated Use of Surface and Groundwater Resources

The ultimate goal of irrigation and drainage management should be to maximize system performance, which means minimizing the amount of water extracted from good-quality water supply and maximizing the utilization of the extracted portion during irrigation. As much water as possible should be consumed in transpiration (hence in producing biomass) and as little as possible wasted and discharged as drainage (Rhoades, 1998). To this end, as long as drainage water still has value for transpiration use by crops, it may be intercepted and recycled for irrigation until its ultimate disposal. This will reduce drainage and the associated water salinization, as well as increase the available supply of irrigation water. It will also reduce water logging and the overall amount of soil salinity degradation in the associated region (FAO and ICID, 1997). This process calls for a new integrated approach to irrigation and drainage management and monitoring in order to (Rhoades, 1999):

- Minimize water use and reduce deep percolation through implementation of more efficient irrigation systems and practices
- Intercept, isolate and recycle unavoidable drainage water by serial reuse. This would reduce drainage water volumes, conserve water and minimize

pollution, while producing useful biomass and habitat

- Promote conjunctive use of saline groundwater and surface fresh water, lower water-table depths, reduce the need for drainage and conserve water
- Monitor the soil salinity concentration to assess the adequacy and appropriateness of irrigation and drainage practices.

Various means should be used to reclaim or dispose of the ultimate unusable drainage effluent that should, however, preferably not be discharged into water of good quality. Moreover, the integrated approach should provide information that feeds into the policy decision process through an iterative exchange among researchers, designers and policy makers, involved in irrigation and drainage. Communication among the different partners should be an essential element of the framework, along with the need for a cross-disciplinary approach in order to develop environmentally sound strategies and policies. Finally, the results of this integrated approach, both in terms of the understanding of existing irrigation and drainage systems and of the potential impact of management and policy changes, should be communicated to and shared with stakeholders (De Wrachien and Fasso, 2002).

B-Institutional and Financial Aspects

Institutional strengthening and proper financial assessment are essential tools for efficient planning, design and management of irrigation and drainage systems. Without a sound institutional framework, at the national or river basin levels, it will not be possible to promote and ensure sustainable water management for agriculture (El Quosy, 1993). Economic constraints are equally important. The cost of system improvement is normally substantial and governments, in an era of transition from state to a market economy, will not be able to continue financing irrigation and drainage activities, as they used to do. The new philosophy is based on the principle that the services must be paid for by those who benefit from them. Sustainable development, as defined earlier, should, therefore, meet two basic requirements, namely institutional strengthening and economic viability. To this end, there is a pressing need to apply appropriate institutional and financial analyses in all phases of project planning and evaluation in irrigation and drainage system development.

With respect to this the issues of responsibility and cost recovery deserve special attention, especially while this issue is very important related to the sustainability of modernised systems.

Institutional Issues

The last decade of the 20th century was marked by the change of the global economic system from state to market oriented in almost all countries of the world. The immediate reflection of this change on agricultural production was the movement from subsidized towards privatised farming and a more free marketing of farm products. While on the one hand, privatisation means less involvement of governments in improving services and welfare, on the other moving towards a market economy requires enhancing the quality of production in order to be able to compete with similar products worldwide. In the meantime, public awareness about pollution and environmental issues is increasing. All this leads to the main features of agricultural development in the twenty-first century, namely:

- Less dependence on government support
- High level of good quality production
- Less soil, air and water pollution.

In this context operation, management and maintenance of irrigation and drainage systems should also be improved. Government expenditure on agricultural activities will be reduced and farmers, generally the major beneficiaries of the water management, will be expected to take over responsibilities. As individuals they can do little. As groups and organized in associations they will probably be able to do what is required for sustainable operation and maintenance. Obviously the transfer of systems from state to private sector will involve lengthy and slow processes in which each party will try its best to defend its ideas and interests.

Moreover, the laws and rules that regulate different aspects of water use and related subjects are often old and outdated. If these laws and rules are not dynamic enough to cope with the rapid changes taking place in society, they no longer reflect the changing social-economic situation of groups and individuals. As a result, the formulation of concepts and ideas on the shape and structure of the expected institutional and financial

interrelationships in irrigation and drainage systems management is today one of the most important issues to be addressed in order to clarify the role each party plays and to avoid conflicts. To confront these challenges, the attention, research and expertise would have to focus on:

- The role of governments, governmental institutions and private sector in maintaining effectiveness of irrigation and drainage systems
- The interactions between governments, governmental and private organizations at the strategy planning and operation levels
- The processes by which the redefined level of service should be determined and specified
- How the cost of redevelopment and ongoing operation and maintenance required to provide the agreed levels of services, should be determined and recovered or shared.

Financial Issues

For the proper functioning of irrigation and drainage systems a hydraulic infrastructure is required able to manipulate surface and groundwater flows and levels. The development and management costs of this infrastructure need to be recovered from the beneficiaries or from the community if the system is to be sustainable. This necessitates a sound financial management system in which revenues from service delivery cover the associated cost (Hofwegen, 1997, Hofwegen and Malano, 1997).

To link all the financial aspects related to irrigation and drainage system management, a conceptual framework is needed, based on the assumption that the system is intended to be sustainable, or in other words on the guiding 'user pays' principle. This requires identification of beneficiaries or clients for the services provided. A clear definition of the clients is necessary to determine with whom to enter into a service agreement, who to charge and where to send the bill. Service levels are set according to operational standards and quality criteria. Operational standards govern the system management and serve two purposes:

- To provide a set of rules against which the operational performance of the system can be measured
- To provide a set of rules that governs the delivery of the service.

The quality of service provision can be defined as a combination of parameters concerning the adequacy, flexibility, convenience, cost and security of the services provided. Delivery of services requires the design, construction, operation, maintenance and eventually the replacement of a hydraulic infrastructure. Resources are needed to cover the costs of managing the system, deriving essentially from:

- Operation, in relation to the number and skill level of the staff required for operating the structures and associated equipment
- Maintenance, determined by the number of control units and their individual costs
- Depreciation, which allows for the wear and tear of the infrastructure.

An increase in service level will automatically imply enhancing management performance or upgrading the infrastructure or both. So a trade-off between investment and management performance is desirable if a certain level of service is to be achieved, on the understanding that the service level is part of the overall management objectives.

In summary, clear service agreements and effective accountability mechanisms are essential for reliable service as a direct relationship is thus created between service requirements, level and cost on the one hand and the payment for services on the other. To minimise fluctuations in costs, hence service fees, proper planning of service cost is essential. For this purpose, a reliable asset management plan is an indispensable tool.

C-Research and Development

Insufficient research, application of research findings and access to new and advanced technology in the sector were seen as some of the main reasons for the problems plaguing the sector: poor water use efficiency, environmental degradation, high costs and lack of responsiveness to beneficiaries. Since then, many technology research programs have been launched by different scientific, financial and professional institutions. Their mission has been to enhance the standard of irrigation and drainage research and development, at worldwide level, with a view to improving technology and management so as enhance system performance, food security and sustainability of the irrigation and drainage environment.

Priority Issues

In fact the major issue is the affordability of the application of new technology. Generally the technology is there, but the incentives to apply it are missing. Research priorities were selected for their potential contribution to alleviating the above constraints, while the relative importance of the issues to be addressed would vary depending on the needs of a particular country or region (World Bank and UNDP, 1990). In this context priority issues include all aspects for controlling the adverse impacts of irrigation and drainage on soil and water quality. They cover field and laboratory evaluation, assessment and monitoring, development of guidelines and implementation of appropriate irrigation and drainage practices.

The need for new irrigation technologies and management procedures at the farm and system levels was particularly stressed. This requires enhanced field research and a wide variety of tools for field techniques such as land levelling, equipment and advanced technology for water control and regulation, models, remote sensing, geographic information systems, decision support systems, computer image analysis, sensors, neural network technology. More accurate estimation of crop water requirements is also required along with a better understanding of flow and mass transport phenomena in the soil-plant-atmosphere system, and of the interactions, feedbacks, hydrodynamic and hydrochemical processes occurring in the porous media, to improve both yields and incomes. All these tools have to be considered adopting a broad and integrated approach that embraces food and agricultural commodity production, water saving, resource conservation, environmental impacts and social-economic effects.

Particular attention was focused on the problem of water quality and modernization of irrigation and drainage systems in those regions where water scarcity and the vulnerability of soil and groundwater to salinization call for special measures for rendering water management for agriculture sustainable. Moreover, appropriate management tools, such as efficient conjunctive use of surface and groundwater resources, have to be made available to exploit saline and low quality water without decreasing the production potential and the carrying capacity of these fragile and valuable agro-ecosystems.

To face these challenges, the attention of research would have to be focused now and in the years to come, on the following main themes (Pereira *et al.*, 1994):

1. Viability and affordability of irrigation and drainage

- Role of irrigation and drainage in sustainable agricultural production systems
- Determination of optimal approaches to modernization of irrigation and drainage systems and resulting operation and maintenance.

2. Crops and water use

- Evapo-transpiration and related calculation methods
- Estimation of crop water requirements
- Improved knowledge of water-fertilizer-crop production interrelationships.

3. Irrigation and drainage systems

- Procedures for integrated planning, design, operation and maintenance
- Analysis to identify causes constraining system performance
- Strategies to improve system efficiency
- Technologies for system modernization
- Environmental impact and suitable measures to create and maintain sustainable conditions.

4. Institutional and financial aspects

- Development of service agreements under conditions as prevailing in the emerging developing countries and the countries in transition
- Farmer's capability to contribute to agricultural water management.

5. Use of saline and waste water

- Flow and mass transport processes under irrigated agriculture
- Methods and techniques for use, control and management of low quality water
- Adaptation of crops to low quality and brackish water
- Conjunctive use of saline groundwater and surface fresh water.

Strategic Action Program

The above described themes and principles tackle the root cause of the major problems encountered in irrigation and drainage system development. To be effective, they have to be translated into actions through the formulation of

programs that take into account the actual conditions of the environment where they are expected to be implemented. These programs should include (FAO, 1990):

- The adoption of a comprehensive approach that considers land and water use and management and the environment in an integrated manner
- The promotion of regional co-operation to ensure that the concerns of all parties are translated into sound decisions
- The recognition of the relationships between different land uses and availability of water resources (quantity and quality)
- The encouragement of broad based participation, including governments, professional and research institutions and non-governmental organizations
- The endorsement of phased programs of action at the national and local levels.

This regional approach makes up and outlines the body of a Strategic Action Program, a crucial procedure for implementing priority actions at both national and local levels. The objectives of the Strategic Action Plan are to (Hamdy and De Wrachien, 1999):

- Evaluate trends
- Assess causes and implications
- Review of optimal interventions with their legal, economic and financial implications
- Provide a cost estimate for investments
- Establish a framework for monitoring and evaluation
- Identify priority actions to address key issues.

Priority selection should follow the criteria listed below:

- Ensure optimisation of interventions, in order to concentrate resources on significant problems
- Pay due attention to both technical and non-technical aspects (human resources development, legal and institutional aspects, environmental impacts)
- Avoid duplication and overlap
- Emphasize adaptive and cost effective solutions through adaptation and/or improvement of existing technology to specific tasks
- Select topics for investigation and research that are likely to achieve the greatest benefit, considering return on investment, response time, probability of success and impact on agricultural production.

This integrated approach is expected to produce significant benefits in environmental and economic terms, a more sustainable use of land and water resources in irrigated agriculture and higher yields and incomes.

D-Human Resources and Networking

Successful technology and research activities in irrigation and drainage development depend on the number and quality of human resources (professional and research related people) involved. They use their knowhow and skill to solve priority problems and adapt available techniques to local situations. This expertise will have to include the ability to:

- Identify local hurdles and constraints
- Formulate research strategies
- Design suitable technologies for testing, monitoring and evaluating
- Assess the technical, economic and institutional aspects concerning the application and adaptation of modern and advanced technologies.

Moreover, these experts will have to assist national and international agricultural and irrigation and drainage institutions to improve training in water related topics, as well as scientific organizations to identify subjects that warrant further analysis and investigation. Such a collaboration framework is imperative if the proposed initiatives are to be integrated into ongoing activities. To this end, the establishment of an effective networking system can greatly facilitate collaboration and integration. This will require an interdisciplinary, multi-sectoral approach, using a system-engineering methodology, to recognize the necessary interrelationships. The nodes of the network will be organizations, institutions and agencies, as well as professional, academic, commercial and industrial bodies. The aim is to create a permanent structure able to:

- Speed up the process of collection, selection and exchange of information, avoiding duplication and overlap
- Build up synergies among the partners
- Interact with other frameworks
- Seek financial support to reinforce local activities of particular interest

- Provide an international forum for debating irrigation and drainage problems and finding sound and environmentally sustainable solutions.

Recommendations

1. Meeting human food and fibre needs without jeopardizing the resource base and the environment will continue to pose major challenges to decision makers in the decades to come.

2. The prospects for expanding the gross cultivated area are limited by the dwindling number of economically attractive sites for large-scale new irrigation and drainage projects. Therefore, the increase in agricultural production will rely largely on significant improvements in the performance of existing systems.

3. Irrigation water use efficiency is crucial to satisfying the food and fibre demands of present and future generations. Worldwide, overall irrigation water use efficiency is about 40%. So there is no doubt that introducing advanced technology such as innovative systems designed for low-energy-precision application can enhance efficiency from the current levels up to 80 - 90%, comparable with drip irrigation. Lining canals, preventing leakage in distribution systems and new equipment for water control and regulation can contribute significantly to the improvement of the productive use of water. In addition a new paradigm needs to be introduced to rethink the concept of water use productivity. To this end, two approaches should be pursued: increasing efficiency with which crop requirements are met in an optimal way and increasing the efficiency with which water is allocated to the different demands.

4. With regard to the modernization of existing systems and the installation of new ones, several aspects deserve consideration such as: determination of required level of service, interaction between water management and crop yields, effects on local surface and subsurface water resources, disposal of unusable irrigation water, environmental impacts (water logging and salinization). On the whole, the success of irrigation and drainage projects is strongly linked to the creation of a favourable environment that will attract farmers to commence and continue the proposed activities.

5. An integrated approach to irrigation and drainage development is needed, so as to maximize water application, reduce deep percolation and intercept, isolate and recycle low quality water effluents.

6. Designers and managers will have to rethink design criteria, operating rules and water allocation policies. In this regard, management strategies should extend not only to resources, but also to demands.

7. In an era of transition to a market economy, governments will no longer be able to continue financing irrigation and drainage systems at the level they were used to do. The private sector (mainly water user associations) should gradually take over the tasks performed by public administrations, such as operation and maintenance of existing infrastructure. To this end, user associations should improve their own capacity building, by increasing their technical and financial resources. Also the financing of new infrastructure will require beneficiary participation. Modernization of irrigation and drainage projects should to a large extent rely on self-financing, with the beneficiaries procuring private funds.

8. Public administrations and water user associations should devise suitable means for achieving consensus on the principle 'intrinsic versus economic value of environmental assets'. In other words, the right balance needs to be struck between productive water use (for food and fiber) and the need to improve our environment (fundamental to the quality of life).

9. Successful technological innovation in irrigation and drainage development depends on broad research programs and on the number and quality of human resources involved. These programs and resources must be closely linked with national institutions and international agencies so that an efficient networking can be established in order to find environmentally sound solutions to operational problems and provide an international forum for debating irrigated agriculture issues.

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