REVIEW OF RESEARCH AND DEVELOPMENT
NEEDS IN IRRIGATION AND DRAINAGE

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Preface

Irrigated agriculture makes an important contribution to food production and rural development in many poor countries of the World. Long lasting benefits of irrigation and drainage development can only be achieved through methods that preserve the productivity of water and land resources that, in many cases, are already under stress. Research in irrigation and drainage is therefore crucial if our knowledge to use water wisely is to be increased, improved and applied.

During the past three decades, the uptake of irrigation and drainage technology in developing countries has stagnated. This has been in part due to a decline of good quality research and adherence to conventional technologies and practices. In addition, there has been little adaptation of the significant technological advances in developed countries to specific local conditions in the developing world. Promoting irrigation and drainage research in developing countries is, therefore, critical if irrigation and drainage developments are to be sustained.

The International Programme for Technology and Research in Irrigation and Drainage (IPTRID) was established in 1991 to promote technology and research in irrigation and drainage in and by developing countries. Part of the process of promoting good quality research by research institutions in developing countries is the identification of gaps in knowledge that if filled would improve irrigation and drainage. For this purpose, IPTRID has carried out a review of research needs to fill these gaps. The objective is to provide guidance to research and development institutions to identify research priorities and formulate programmes of research. The review also enables IPTRID to direct its awareness creating and promotional work and provides for a better focus to its research and development country missions.

The document considers previous reviews of research needs as a background to the current assessment. Problems associated with the present and future use of water for agriculture are then analysed to identify areas where research could assist in meeting appropriate development challenges. The primary focus has been directed to technical issues. However, to be sustainable, technological advances must be compatible with local socio-economic and institutional environment so for this reason, relevant non-technical issues have been considered.

It is hoped that this review will stimulate researchers and irrigation and drainage professionals in developing and developed countries alike to reflect on future research needs and to better plan and implement relevant and good quality the research programmes. We should not forget that the goal is to promote sustainable agriculture, because agriculture is the cornerstone of development in poor countries, where over 70 percent of the people depend on farming for their livelihoods. Timely and relevant research in irrigation and drainage can play a significant role to achieving this goal.

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The World Water Vision for 2025, as expressed by the World Water Council (WWC, 2000), was motivated by the growing global water crisis. Throughout large parts of the world, limits on the available water resources are in sight. Agriculture must increasingly compete for available water in the struggle to feed growing populations. Greater output is required per unit of water and per unit of investment.

At present, the irrigation sector uses water inefficiently in many parts of the world, constrained by institutional, technical, social and budgetary factors. The objective of the review is to identify where research and development, particularly in technical areas, can help to improve performance of the sector. In the process, the aim was to identify where there are gaps in the focus of current research. In the face of water scarcity, the needs of one set of water users cannot be considered in isolation from those of others. That reality has led to the identification of a number of research issues, which span the boundaries between irrigation/drainage and other water disciplines (Gaps), and have not yet been addressed.

Previous reviews of research needs (Key References) were initially analysed to provide the background to current assessment of needs. The problems affecting the use of water for agriculture were then identified so as to analyse where research and development were an appropriate response. The outcomes were compared with the findings of the Key References and of IPTRID country missions to establish national R&D needs.

As indicated, the primary focus has been directed to technical issues. However, experience shows that to be sustainable, technological advances must be appropriate to the local socio-economic and institutional environment. For this reason, relevant non-technical issues were identified.

The research issues identified were assigned to categories of priority. Primary allocation criteria were the significance of an issue (critical, urgent or important) and the scale of the underlying problem (global, regional). Six categories were drawn up, made up of the three significance levels applied at both regional and global level. The aim was to ensure that problems affecting a region or nation were not under-rated. Viewed in global terms an issue might seem to have lesser weight, whereas in regional terms it might be of huge significance. Account was also taken of whether the issue had been identified previously in the Key References and IPTRID missions, and of the potential impact of the research on livelihoods (major, minor, neutral). There is no particular ordering to the issues within a category.

Most of the 31 issues in Table 1 include several of the topics identified in section 2. Categories A (Critical–global) and B (Critical–regional) issues tend to deal with problems of water scarcity, involving institutional, technical and economic aspects, and disposal of excess water. Categories C (Urgent–global) and D (Urgent–regional) issues cover a variety of subjects including prioritization of rehabilitation and maintenance works, impacts of globalization on small farmers, integrated rural water developments to reduce women’s tasks, low cost ways of treating polluted land and water, problem diagnosis for maintaining drain performance, cost-effective ways to reclaim problem soils. Categories E (Important–global) and F (Important–regional) issues include, inter alia, effects of climate change, impacts of irrigation on environment and health, basic guidance to engineers on social issues, crop response to drainage, energy-efficient small pump sets. Gap issues are identified. Parallel actions are identified, which need to be undertaken by governments, research organizations, or by IPTRID itself, as appropriate, to derive full benefit from the research. It was concluded that, as water becomes increasingly scarce, irrigation engineers need to extend their vision beyond the traditional domain of

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1 In some parts of the world the ‘country’ may be larger than a ‘region’ in another part.
the irrigation sector. IPTRID can potentially play a very valuable role in disseminating state-of-the-art information from other sectors/disciplines, including water supply, agriculture, geohydrology, and other water users.

Knowledge of relevant work in other sectors can help the profession to make informed decisions about reducing water use, increasing output and minimizing environmental damage. Issues such as: improved crop varieties, proper tillage, mulching, rainwater harvesting, energy efficiency in pumping or requirements for sustained development, could add value to the immediate focus on technical aspects of irrigation and drainage. In its dissemination activities, IPTRID could consider including articles or issues papers by organisations hitherto not considered.

Technological and scientific advances in such fields as solar power for low-head pumping, improved desalination technologies, bio-treatments for waste waters and polluted soils or genetic engineering of appropriate crops, require substantial commercial research and development inputs. All of these offer great potential to the water sector and thus, directly or indirectly, to irrigation, but they are beyond the immediate research remit of IPTRID. However, the irrigating world will greatly benefit by early dissemination of the results when the technologies are ready for adoption.

This review is intended to provide general guidance to research and development institutions in irrigation and drainage in identifying research priorities and formulating their programmes of research as well as to provide direction to IPTRID in its awareness creating and promotional work and research and development country missions.
**Water for Food**

The World Water Vision for 2025 (WWC, 2000) was motivated by the growing global water crisis. At the start of the third millennium, it was estimated that 20 countries in Africa and the Middle East suffer from absolute water scarcity (<1,000 m$^3$/head/year), compared with 16 countries in 1993 (Van Tuijl, 1993). Throughout large parts of the world, limits to the water resource are in sight.

As the outstanding success of the Green Revolution fades into history, food output per capita is once more in steady decline throughout much of the developing world. Irrigated agriculture is essential to the world’s drive to produce more food, yielding up to five times as much per unit of land as rainfed farming. In critical regions, irrigation can provide the only defence against droughts, which have been predicted to occur more frequently as the climate changes. Yet, lending agencies and donors are steadily reducing their funding for irrigation, despite the fact that projects in irrigated agriculture perform at least as well as those in other sectors (WB, 1994).

In many parts of the developing world, agriculture contributes a high proportion of Gross Domestic Product. However, irrigated agriculture uses around 70 percent of nations’ water, and must increasingly compete for available water with other sectors of the economy. It has been argued that nations can overcome food and water shortages by importing food, or “virtual” water. All the countries in North Africa, with the exception of Morocco, already import a significant proportion of their grain requirements. However, imports have to be paid for, so decisions have to be made whether this option is economically more viable than investment in irrigated agriculture. Also, food is a form of security, its production being widely seen as a stabilizing factor in rural economies.

Many developing nations aim to maintain some target level of self-sufficiency in staple foods, perhaps up to 70 percent of national need, as well as to produce cash crops for export. In the present circumstances, no developing nation can afford to neglect its agriculture, which functions as a fallback for millions of people at times of crisis. More reliable irrigation water supplies will encourage farmers to grow higher-yielding varieties and higher-value crops, thus raising rural prosperity. This, in turn, should counter the trend of population shift to already overcrowded cities.

It is widely acknowledged that agriculture must produce more from a smaller share of the national water budget (“more crop per drop”). The average water use efficiency, the output per unit of water, is at present considerably below potential in many countries. The sector is subject to technical, institutional, economic, financial and social constraints. Free market solutions, involving institutional and policy changes, have had some successes, notably in Mexico and Turkey, which are classed by the World Bank as middle income developing economies. However, despite isolated successes, substantial improvements have still to be realized elsewhere. The question remains: how is irrigated agriculture to increase production sustainably and safely, whilst using a diminishing share of national water resources?

Sanmuganathan (1987) comments—“All nations rely on research to solve problems and this is a generally accepted principle of our political and economic life.”

Innovative and adaptive solutions to increase crop production, based on sound research, are needed. Improved irrigation methods can lead to increased yields per unit of water, of land and of capital.

Integrated planning, to coordinate the development objectives of competing water users, is basic to the World Water Council’s Vision, which aims to set out a framework for water use and management to the Year 2025. The present review of research recognizes the need for interdisciplinary thinking.

**Structure and aims of the review**

Many of the issues which determine the performance of irrigation are not primarily technical in nature. Many will not require research for resolution. The overall aim of the review has been to help research and development organizations in focusing limited resources upon research issues of prime importance for regions, and for the world. It should also be of use to IPTRID in its mission to promote and disseminate relevant research. The researchable issues identified (Table 1) do not necessarily require the direct intervention of IPTRID, but they are all
issues upon which IPTRID should focus its dissemination activities, because, without a broad vision of the problems, many technical interventions may not be sustainable.

There have been many initiatives to identify R&D needs in irrigation and drainage. Sanmuganathan (1992), Carruthers (1992), Pereira (1994) — to name but a few — summarized the outcomes of consultations on research needs. A list of such key references is included at the end of the main text; the findings are summarized in this Chapter and Appendix IA. IPTRID has sent missions to individual countries and regions to establish research needs, focusing on three broad subject areas: modernization of systems; maintenance; drainage and reclamation. A summary of findings of IPTRID Missions is presented in Appendix 1B.

Appendix II includes a synthesis of all this previous consultative and investigative work. The present review summarizes previous research identification exercises, compares the findings with current needs, identifies some gaps, and establishes a priority of research need. Certain research issues have a global or generic relevance, others have overriding importance to a region or to a relatively few countries. An assessment of global priorities will therefore differ markedly in some respects from the priorities drawn up for a region or a nation. For this reason, it is aimed to indicate clearly the relevance and significance of the research.

Chapter 2 briefly analyses the principal problems currently facing irrigation and drainage. It provides an overview of the set of broad problems which need to be resolved. The aim has been to provide a framework to identify problems amenable to research and development, and to compare outcomes with previous analyses. For the purpose of the review, problems and research topics have been considered in the following categories:

- Water Resources
- Land, Soil, Drainage
- Institutional, Economic, Social
- Environmental

It is clearly recognized that, in reality, many of the problems considered in different categories are inter-linked.

It is recognized that there are large numbers of research organisations and university departments investigating various aspects of irrigation and drainage throughout the world. But it was not feasible, at this stage, to poll them all to determine their current research focus and projects. This is an exercise which, with international cooperation, should become a future objective.

The findings of Chapter 2 and of previous work (Appendix II) are combined to reach a set of priority issues in Chapter 3, Table 1. Primary allocation criteria were the Significance of an issue (Critical, Urgent or Important) and the Scale of the underlying problem (Global, Regional). Six categories were drawn up, made up of the three significance levels applied at both regional and global level. Account was also taken of whether an issue had been identified previously in the Key references and/or IPTRID missions, and of the potential impact of the research on livelihoods. In many cases, parallel actions will need to be taken by governments, or research organizations, or by IPTRID itself, as appropriate, to achieve the potential of the research. They are noted in the Table.

Chapter 4 summarizes the conclusions and recommendations of the review.
PREVIOUS IDENTIFICATIONS OF RESEARCH NEEDS

Key references

The key references are included in chronological order. Some of the identifications assigned priorities to research topics, others did not. A more extensive summary of the findings is included in Appendix 1. Since the research agenda identified by any given group of people will reflect their professional discipline, the composition of the groups is indicated in the appendixes.

Many of the issues identified more than a decade ago are still seen as relevant by the irrigation community, but their relative importance may now be allocated a different weight. As an example, in recent years there has been a widespread recognition that inefficient government irrigation schemes are much constrained by human and institutional issues, not just by failings in the technology or in farming practice. Thus, institutional matters have been highlighted for attention.

A Colloquium at Wallingford (1987) on Research Needs in Third World Irrigation, attracted over 70 participants from a broad range of backgrounds. Over 100 topics in water management, planning and design, rehabilitation, agriculture, the environment, socio-economics, institutions, and performance assessment were identified. 43 topics were brought forward for ranking. The need for authoritative data on system performance data was given top priority.

Ecotec (1991), an EC initiative aimed at identifying water research needs in Europe, focused on 17 topics in four categories termed: source exploitation; water treatment; water demand; wastewater management.

Sanmuganathan (1992) pinpointed a large number of issues. He categorized them in five broad areas: increased agricultural productivity and production efficiency; resource conservation and management; sustainable development; multidisciplinary issues; supportive actions.

Da Costa, Carruthers et al. (1992) listed 52 topics in nine categories: modern irrigation methods for small farmers; decision support systems; transnational river basin management and environmental protection; alternative institutional arrangements for water management; strategies for alleviating poverty and social inequities; design for O&M; impact of irrigation on other water users; monitoring and evaluation; optimizing water allocations and impacts of deficits.

Feyen and Mwendera (1992) covered a number of issues: evaluation of irrigation performance; yield response to water; returns to irrigated/rainfed agriculture; management structure and performance; farmers’ organizations and participation; management and organization of projects; irrigation within a watershed.

Nwa and Pradhan (1993) called for work on: performance assessment; economics of alternative irrigation developments; appropriate irrigation technologies; alternative energy sources for pumping; salinity and groundwater; reducing irrigation losses; improved maintenance management; integrated water management at basin level; strategies for groundwater recharge; framework for participation by farmers; sustainability within the environment; sociological studies.

Skutsch (1993), recognizing that many constraints are institutional, social or financial, focused on technical research in irrigation and drainage maintenance: impact of design on maintenance; low maintenance designs; optimal strategies for available resources; multidisciplinary studies of success/failure of technologies; minimizing sediment deposition in channels; biological and environmental methods of weed control; canal linings: their effective life, whole life costs, and suitable repair methods; practical maintenance handbooks in local languages.

The European Commission (1994) focused on four areas: environment and water, including climate change; industrial technologies for saving water and improving its quality; wastewater: improved techniques for treatment, operating plants and networks; improving quality control in water analysis. Thirteen sub-topics were identified.

Pereira, Jensen et al. (1994) defined three basic categories for investigation: resource base issues, amongst which environmental and health impacts were ranked first; irrigation and drainage systems (water quality management ranked first); institutional, socio-economic and policy issues. Fourteen ranked topics were identified.

ICID (1995) identified the broad areas of research of some leading institutions in the irrigation world and research areas where IPTRID could complement them. In particular work to improve food security, water management, technology development were identified. Lessons from IPTRID’s experience to date were set out.

IWMI Medium-Term Plan (1996). In its current plan, IWMI includes four programmes of global research work: performance assessment of irrigation

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**Key references**

- Colloquium at Wallingford (1987)
- Ecotec (1991)
- Sanmuganathan (1992)
- Da Costa, Carruthers et al. (1992)
- Feyen and Mwendera (1992)
- Nwa and Pradhan (1993)
- Skutsch (1993)
- The European Commission (1994)
- Pereira, Jensen et al. (1994)
- ICID (1995)
- IWMI Medium-Term Plan (1996)
and water resource systems; design and operation of irrigation systems, including salinity management; policies, institutions and management; health and the environment.

Franzen et al. (1997) summarize R&D activities by German organizations in the tropics and subtropics. Applied research in surface water management, including turnover projects, and in rehabilitation is called for.

IWMI (Merrey, 1977) summarizes work by the organization in the period 1984-1995 and identifies future directions for irrigation research. Topics in performance assessment; design and operation; policy, institutions and management; health and environment were identified. Institutional strengthening programmes were anticipated.

Abbott and Leeds-Harrison (1998) concentrated on research needs in drainage and soil salinity. Six broad areas were identified: integration of irrigation and drainage to improve unit productivity and save water; drainage benefits and investment strategies; measures to improve performance; drainage and reclamation of problem soils; drainwater disposal and reuse; tools for planning and design

Pereira et al. (1998). The conference focused on environmental issues connected with irrigation, drainage and soil management. Eight topics were defined: integrated approach to environmental issues; effects of tillage on solute movement; long-term effects of irrigating with poor quality water; continued investigation of acid sulphate deltaic soils; appropriate drainage for ecosystems and conservation; performance monitoring; economic, legal, institutional and social issues; gaps of knowledge between policy-makers and professionals

Burton, Kivumbi and El-Askari (1998) divided research needs into three categories: improved understanding: diagnostic methods linking cause and effect in system performance; determinants of farmers’ irrigation practices; consequences for output of poor maintenance; reuse of water vs. improved management; improved management: appropriate performance assessment procedures in daily management; methodology to categorise schemes for appropriate solutions; initiating changes for improved management.

European Commission (1998). The consultation put forward 41 important “research clusters” in five broad areas: integrated water management; water pollution; combating water deficits; preventing/managing crisis situations; and cross-cutting issues. Priorities can be based on the criteria for the 5th Framework Programme: 1) Community value added 2) environmental and social objectives 3) economic and technological development. Priority topics were not explicitly defined in the report.

Perry (1999) suggested that research priorities varied with the size of the irrigation system:

- Micro scale: reliability. “What is the trade-off between the service the farmer anticipates, and the productive use he makes of that service?”
- Intermediate scale: institutional issues.
- Macro scale: better data, and analytical tools to use the data.

IPTRID Country Missions

Between 1991 and 1998 IPTRID completed a series of short expert missions at countries’ request, working with national experts in identifying research needs. Egypt and Pakistan; Mexico; Morocco; China; India; West Africa; Indonesia; Zimbabwe were all visited. Appendix II summarizes the research topics identified for each country.

In Egypt, Pakistan and Morocco, the prime focus was on problems of drainage and soil salinity. Mexico, India and China also have concerns in these areas. Improved techniques for planning, design, implementation and rehabilitation of drains were consistently identified as a need. Reuse and disposal of poor quality drainage waters are generic problems. Techniques for drainage of problem soils were particularly sought in Egypt and Pakistan.

Mexico, China and India sought the best methods for modernising older gravity systems, including operational software. India and the African countries sought appropriate pressurized irrigation techniques and equipment to improve the use of water at farm level. Indonesia, Mexico and the African countries needed better knowledge to make system turnover to farmers fully sustainable.

Most of the countries with large systems — Egypt, Pakistan and Morocco (drainage), Mexico and India — were particularly concerned to improve maintenance identification, planning and methodologies. Mexico, India, Egypt and Pakistan sought better ways of dealing with weed growth in open channels. India, China and Mexico wanted to identify more durable lining materials/techniques which required reduced maintenance.

All countries were in favour of mechanisms to promote the exchange of information. Support to institutions is seen as a general need, but was particularly identified for Africa, Indonesia and China.
Problems affecting water use for agriculture

Overview
The problems and constraints in the use of water for agriculture are well known. They are briefly summarized below so as to highlight prime causes and provide a framework within which to identify research needs. The needs are analysed in turn. The broad areas chosen, such as Water Resources, Land, Soil, Drainage, and so on, are for convenience, but they are not rigid. Many of the problems overlap with other areas. As an example, Water Quantity and Water Quality become inseparable when limits on the available resource are approached. However, the problems affecting water use in agriculture should be included in one or other category.

Problems Affecting Irrigation and Drainage
In the following, problems affecting irrigation and drainage are listed under broad headings.

Water resources
Water quantity
- Limits on the overall water resource. Existing surface resources are increasingly utilized, groundwater supply is being over-drafted in many areas. Deep fossil water is being mined in some areas of the Middle East, with short-term exploitation in mind.
- Irrigated agriculture seeks more water to grow more food. However, demand for industrial, domestic, and environmental uses supply is also increasing rapidly; water is used inefficiently in agriculture. There are large losses in conveyance, up to 50 percent in small field channels, and in application, up to 60 percent.
- Excess water causes crop losses, waterlogging and soil salinity.
- Climate change is predicted to increase temperatures, reduce rainfall and increase its variability in some regions already experiencing water stress.

Water quality
- Surface and groundwater supplies are being increasingly polluted by agricultural, domestic/urban and industrial use.
- Groundwater containing naturally-occurring ions like arsenic and iron is increasingly being used, causing problems in drinking water supplies and in agriculture.
- Saline intrusion follows over-drafting of coastal aquifers in many arid/semi-arid areas.
- Secure strategies to improve groundwater quality cannot be evolved because basic data on aquifer characteristics are rarely available.

Water sharing
- Coordinated policies to develop and share available surface water between different users rarely exist at catchment level; concerted policies for regions and nations are even rarer.
- There are no existing models or mechanisms for sharing groundwater resources, particularly where they underlie national boundaries.
- Distribution between farmers on surface irrigation schemes is generally inequitable, even where water rationing operations (for example, warabandi) are imposed.

Land, soil and drainage
- In many areas of the developing world, except parts of Africa, there are few new areas of suitable agricultural land which can be economically developed using existing water resources.
- Marginal lands are being over-exploited and degraded under excessive population pressures.
- Productive land is being lost to rapid urban and industrial development.
- Some 30 million hectares of land world wide are affected by continuing problems of waterlogging and salinity.
- In water-short areas, soil is being degraded by irrigation with brackish water.
- In arid areas, the long-term effects on soil structure of irrigating with low quality urban effluent are uncertain.
- Economic techniques for reclaiming large areas of problem soils have still to be developed.
Institutional, economic and social

(a) Lack of finance, low returns

- Agriculture provides low returns compared with other uses of water. National finance departments are therefore reluctant to commit resources to irrigation.
- The design of the irrigation infrastructure often constrains smallholder farmers to growing a narrow range of crops, frequently cereals.
- The costs of water service fees in much of Asia have been allowed to fall significantly in real terms over the years. Fee recovery is also often poor. For example, in 1992 in India the Government Maintenance Finance Committee recommended a rate of $10-17/ha, whereas only $4-8/ha were actually collected. Gulati and Svendsen (1994) found the recovery rate was less than 50 percent, though it had been 100 percent in the 1960’s. Resources are therefore inadequate for effective O&M.

(b) Lack of sustainability, poor maintenance

- Many small irrigation schemes, particularly in Africa, lack informed support.
- Many irrigation systems are deteriorating prematurely due to poor maintenance. In consequence, water supplies become increasingly unreliable and inequitable, land goes out of production, crop yields fall and the infrastructure is at risk of failure.
- Available maintenance resources may not be allocated in the most efficient manner.
- O&M staff are often untrained in specialist disciplines needed and poorly motivated (and poorly paid).

(c) Situation of the poor

- In 1998, the World Bank (1999) estimated that there were 1.2 thousand million people subsisting on less than $1 per day (24 percent of developing world population), and 2.8 thousand million with less than $2 per day. Many of the poor are landless — sometimes as the result of conflict — with no assured access to water. Water rights are increasingly fully committed.
- Poor farmers without collateral may be unable to obtain credit for the inputs needed to obtain good returns from high-yielding crops. A single crop failure can cause them to lose their land if it has been mortgaged against inputs.
- Women, particularly in Africa, are principal users of water, both for domestic supply and for agriculture. There is no attempt to plan water developments so as to reduce their tasks.
- Many of the poor struggle to afford basic food, though world food prices are at historic lows.
- Poor farmers who migrate to the cities to engage in informal cash cropping in the peri-urban area use water of whatever quality is locally available. They lack support, being outside formal systems, often have makeshift sanitation arrangements, with accompanying risks for health and the environment.

Environment

- Inadequate maintenance leads to silted and weed-infested channels, encouraging water-related diseases like schistosomiasis and malaria.
- Reservoirs are silting up at increasing rates as catchments are denuded. Between 1980-2000, global storage capacity increased 25 percent, whereas lost capacity increased 140 percent, to stand at 10 percent of total capacity.
- Increased use of agrochemicals. Long-term impacts on human health and the environment are unknown. In the short term, fertilizers/pesticides end up in drains, promoting accelerated growth of weeds and algae, and in aquifers.
- Genetic diversity is being reduced as a few high-yielding crop varieties predominate. The impact of a sudden outbreak of disease could be potentially devastating. Genetically modified crops offer potential but also bring extra risks to farmers’ livelihood, as well as to the environment.
- Reuse of saline water can create long-term problems (see Land/Soil). Disposal of saline water to sinks creates permanent degraded sites, with risks for future groundwater quality.
- Food grown on black water and sewage sludge potentially involves risks to human health. Increasingly tight standards of hygiene in industrialized nations may bar developing countries from exporting their produce.

Water resources

Water quantity

Limits on resource

Although global averages indicate that water availability per person is about double present consumption, such figures are irrelevant in the context
of water for agriculture. The distribution of the resource in space and time is very uneven, often requiring large engineering investment make it a sustainable input for agriculture. There is a limit, rapidly approaching, on the physical potential for large surface water conservation and transfer projects. Attention is, therefore, turning to the fundamental role groundwater plays in water resources availability.

Integrated policies to make the best use of surface and groundwater resources, and to deal with water shortages, are generally lacking. Data on groundwater may be inadequate to draw up strategies for sustainable use. Precautionary policies on groundwater extraction have generally not been enforced.

In many countries, the only real constraints on the development of groundwater have been unsuitable geology or lack of capital to construct bore-wells. Groundwater developments are rarely coordinated with surface supplies. Since the advent of privately-owned shallow tubewells, rule-of-thumb recommendations for well spacing have generally been ignored. The water table is being over-exploited in many areas, causing shallower wells to run dry unless centrifugal pumps are set lower down. Where water is short, marginal quality supply may be used for irrigation, causing reduced crop yields and long-term problems in the soil. In a number of regions, aquifers are being polluted, mainly by agriculture.

Potentially, groundwater stored in suitable geological strata can form a buffer resource during droughts. However, informed policies to govern issues such as: conjunctive use; sustainable exploitation of aquifers; recharge; aquifer rehabilitation and protection are rare. In some countries, fossil water is being mined, as a short-term measure. Formal rights to exploit the resource are uncommon. Measurement networks to monitor the state of the resource are rare. The following actions are proposed:

- Sound policies require good information from field monitoring to develop valid models.
- Very little formal monitoring is undertaken. Reliable monitoring systems need to be established.
- Since agriculture increasingly makes use of groundwater (in India, groundwater irrigates a greater area than surface water) there is an urgent need to target multidisciplinary research to quantify the problems so as to direct workable strategies.
- Governments need to develop flexible strategies to deal with water scarcity.

"New" sources of water and energy

In some arid/semi-arid areas of the world, such as coastal parts of the MENA (Middle East and North Africa) region, desalination of brackish or saline water for potable and industrial use could make an important contribution to the supply side of the regional water balance equation, provided the unit costs can be reduced. The best desalination plants at present use about 30 times the theoretical minimum energy requirement to remove salt from water, compared with projections of ten times the theoretical value. It has been forecast (World Water Vision, 2000) that the costs of treatment per unit of water, currently $0.4/m³ (brackish), $0.9/m³ (saline), will fall to $0.15-0.25/m³ (brackish) and $0.25-0.50/m³ (saline) before 2025. Introduction of improved technology, based on reverse osmosis or other methods, must be a high priority for nations which lack fossil energy resources.

Solar power continues to offer potential for agriculture in the hottest regions of the world, particularly for powering pumps and pressurized irrigation equipment. Indications are that the unit cost of solar energy continues to fall. It will be important to develop more efficient pump/prime-mover combinations to exploit improved energy conversion processes. Proposed actions include the following:

- Promising developments in commercial research to improve process and energy-conversion technologies, should be monitored and disseminated.
- The need for more energy-efficient pumping sets to match improvements in energy conversion needs to be investigated.
- Cost-effective technologies are needed now in a number of water-short regions.

Climate change

In some arid/semi-arid regions, like the MENA, climate change may have seriously adverse implications for irrigation and agriculture generally. Initial estimates suggest that by 2050, summer rainfall in coastal North Africa may decrease by 20-25 percent over present mean values, and winter rainfall by 10-15 percent (Ragab, 1999). There will therefore follow an increased demand for irrigation water. The following actions are recommended:

- National water plans need to take account now of possible climate changes in coming years so that precautionary strategies can be developed.
- Initial predictions for specific regions of the world are beginning to become available, but refined estimates are needed as more powerful methods and longer data series become available.
Problems affecting water use for agriculture

Poor water use performance of agriculture

The present unrestrained demand for irrigation water can potentially be reduced if the effectiveness of rain-fed agriculture can be improved. There are now a number of large rainwater harvesting programmes underway, some with international funding, but improved crop varieties for dry areas are still needed. Better knowledge of irrigation system performance has consistently been sought to guide design, improve management and direct the identification of improvement works.

There are various possible strategies for improving irrigation water use efficiency (WUE), the output per unit of water, but there is no formal guidance for governments on the likely benefits to set against the costs of: (1) reduced losses in conveyance; (2) improved application methods; (3) improved management; (4) water reused from a variety of sources (see section Water quantity); (5) demand management, increased water prices and/or introduction of water markets (see section Poor sustainability, lack of finance); (6) crop breeding and biotechnology to reduce water requirements.

Recommended actions include:

- The outcomes of successful rainfed production strategies need to be analysed and disseminated widely.
- Promising new crop varieties need to be promoted with the vigour characteristic of the Green Revolution.
- With increased emphasis by governments on devolution of responsibilities for O&M to farmers and the current consideration of institutional change in management-autonomous or private sector irrigation agencies, there is an urgent need to establish realistic benchmark levels of service.

Reduced water losses in conveyance

Upwards of 20 percent of the water supplied to open channel systems may be lost in conveyance, either to the groundwater or to tail drains. On small systems including earth canals, losses are frequently much higher. Water could be lost to the system, or it might be recovered for reuse elsewhere. However, in a closed basin, there are penalties attached to inefficient distribution and recycling of water: reduced water quality; possible problems of waterlogging/soil salinity; inequity of supply between farmers; costs of re-pumping water. There is therefore good reason to reduce local losses.

Operational losses (start-up and recession flows, slow/inappropriate response to demand, inequitable distribution) contribute to total conveyance loss. Material improvements in irrigation management on a government system depend on institutional change. Automated distribution systems, if properly designed and maintained, can reduce operational losses, but they may not be sustainable in some regions. Technical solutions to reduce seepage, such as channel lining and piping, are popular with farmers, but they need to be maintained. Low pressure pipes, involving few outlets and simple operations, can be successful for small groups of farmers. The following actions deserve careful consideration:

- Lining will considerably reduce channel losses for a time. However, the effective lifetime of lining may be curtailed by inadequate maintenance. Cost-effective methods for restoring the impermeability of existing linings within short maintenance periods are urgently needed.
- In some areas, groundwater currently extracted by farmers is replenished by canal leakage. In such cases, the overall impact of reduced seepage needs to be carefully analysed.
- Piped conveyance can greatly improve supply and equity at quaternary level on pumped systems. If encouraged by successful local examples, farmers can easily introduce such improvements.

Improved application methods

Depending on irrigation application method, surface application efficiency can be as high as 70 percent-80 percent, but may be as low as 40 percent in small farms on coarse soils.

Farmers’ practice is constrained by tradition, their need for basic food security, and the limitations of the public irrigation infrastructure, which is generally designed to produce basic foodstuffs. Faced with uncertainties of climate and unreliability in the system, farmers will adopt conservative strategies, applying more water than the plant immediately needs. Improvements to traditional methods can be made on pumped schemes, by applying water in basin irrigation by hoses or pipes, from one or both ends of the basin.

There is a hierarchy of pressurized irrigation technologies extending from relatively cheap, ‘divisible’ equipment to large scale mechanized devices. Small farmers around the world can manage basic improved technologies to grow higher value
crops for market, provided that they have support from dealers, from extension workers and from credit agencies. In Kenya, small farmers using gravity head sprinklers achieved application efficiencies of 75 percent, compared with 55 percent by surface methods. Farmers, particularly in the peri-urban area, can supplement their incomes by cash-cropping from sources which might not otherwise be viable. Parts of traditional irrigation schemes, particularly at the tail-end where water is short, might be adapted for low pressure improved methods, with or without conjunctive use of groundwater.

Improved irrigation methods can reduce unit water use. Positive policies from government and basic support from the private sector are essential. Despite some successes, the challenge remains to develop and promote technologies which can be sustained by small farmers.

Proposed actions are:

- Realistic pricing of water is needed to encourage farmers to economize on water use.
- Locally adapted and proven improved irrigation methods will have to be documented and disseminated.

**Improved management**

Water use efficiency in agriculture is strongly influenced by main system water management. The scope for exercising improved control over water distribution is determined by: (1) the availability, skills and motivation of operating personnel; (2) the physical infrastructure (gates, weirs, escapes, etc.) – certain combinations of control structures are inherently more suitable than others; (3) the clarity, precision and flexibility, or otherwise, of the operating rules

For systems involving manual operation, all three aspects must be favourable to achieve good management. For automated systems, the constraints appear fewer. However, automated systems can lead to considerable inequities of supply at times of water shortage, encouraging farmers to interfere with the control structures.

Improved management may require new institutional structures, goals and working practices (Section 2.4). Realistic benchmarks by which to judge service performance need to be developed. Quicker and less labour-demanding methods of water measurement are needed.

Aids to planning and scheduling water distribution, based on microcomputers (decision support systems), have been developed, but they depend on institutional support to achieve lasting improvements. Actions to be undertaken include:

- Research and guidelines based on it can help by recommending appropriate management systems and hardware, whether modernized or more traditional, when systems need to be improved.
- Lessons should be derived from performance studies, such as those being promoted by IWMI, ICID, World Bank and others, and widely disseminated.

**Improved crops/biotechnology**

Current initiatives, notably by CGIAR centres like ICARDA and IRRI, are aimed at breeding crops which: (1) Require less water per unit of current output (water scarcity conditions; resistance to stress); (2) Produce increased output per unit of water, and (3) Possess increased salt-tolerance

Crop varieties requiring lower doses of chemicals and fertilizers, are suited to marginal lands, and are more productive under rain-fed farming, are also under development.

The biotechnology industry is currently investing large sums in the development of genetically-modified (GM) crops displaying different characteristics. Some technologies appear to offer considerable potential. However, developing countries are concerned that certain products will threaten the livelihood of small farmers. Environmental concerns also focus on the development of crops tolerant to large doses of herbicides. Some areas for action include:

- Crop responses to water under field conditions, as opposed to trials, need to be documented.
- Further research work to identify and introduce more appropriate crops, in particular, saline-tolerant and water-sparing varieties, is required. Irrigation professionals will need to be advised of improved crop characteristics, so potential savings in water can be realized.
- Genetically modified (GM) crops which are suited to small farmers in the developing world, rather than to industrial farming, are needed. Easier access to GM material by poorer farmers should be encouraged.
Water quality

Water quality problems become more pronounced as limited resources are increasingly reused.

Many aspects of non point-source pollution need to be researched. Increasingly, water from agricultural drainage, urban and industrial effluents is being reused for crop production. Existing guidelines for blending and reuse of water of different qualities, are based mainly on experience in the developed world. The long-term effects on aquifers, soil, human health, and the environment in many different regions and climates, are unknown.

Biotechnological processes offer promise of more economic treatment of waters currently too polluted for reuse in agriculture. Recommended actions are:

- Regional studies to establish baseline concentrations of salts, micro-organisms, algal growths, toxic elements and heavy metals are urgently needed.
- Simple, rapid and low-cost methods of monitoring are now becoming available, but details need to be widely disseminated.
- Improved predictive techniques, defining the impact and movement of pollutants in aquifers, are required to inform water reuse and mixing strategies, recharge policies and to guide the rehabilitation of degraded sources.
- Commercial research is already focussed on biotechnological methods for treating polluted waters, but new technologies need to be affordable to developing countries.
- Modification to technologies may be needed to achieve effective operation at different ambient temperatures with different qualities of effluent.
- Guidelines would help agencies make informed decisions about whether to treat water at source or at point of use.

Water sharing

As water becomes increasingly scarce, strong and effective mechanisms for sharing the resource equitably amongst different users and sectors become vital. From the field right up to international level, arrangements for sharing water are rarely effective when there is a threat to an individual’s, or a nation’s, supply. There are many parts of the world where reallocation of the available supply amongst users could have profound demographic and socio-economic implications. In the developing world experience is needed about establishing viable arrangements for sharing water, and in guidance for reducing conflicts between, for example:

- Domestic water supply, industry and agriculture, particularly in the peri-urban area
- Surface and groundwater supplies, particularly where marginal quality, brackish or ‘black’ waters are used
- Irrigation, aquaculture, and various environmental uses, including wetlands

At the national level, FAO, the World Bank and various donors are supporting initiatives to establish reallocation policies in a number of countries, but there are formidable institutional and social obstacles (FAO, 1996).

At present, international law offers little concrete help in resolving transboundary surface water conflicts. No legal framework governs the allocation and use of international waters; the use of water for ecosystems is not widely recognized.

There are no international agreements on sharing common groundwater resources. In aquifers shared by nations, for example those underlying Israel and Palestine, problems of water quantity and quality are particularly contentious. There are a number of international agreements covering shared surface water resources, but there is still no precedent for political agreement about the use of shared aquifers, although steps are being taken to address the issues (EXACT, 1998). Pilot agreements, incorporating formal monitoring systems, are urgently needed by the international community.

Reliable basic data and effective analytical techniques upon which to base agreements are widely lacking. Proposed recommendations include:

- There is general consensus that agriculture uses too much of the available water resource. However, the most cost-effective ways to reduce water use, and the mechanisms under which the sustainable supply can be shared out between different sectors, are not clear. Working pilot projects, to provide basic information for effective water resource planning, are urgently needed.
- There are currently a number of international initiatives to introduce more rational management of groundwater. Working examples for the sustainable development of groundwater are urgently needed to convince governments that action can, and must be taken.
- Clear policies and mechanisms are needed to regulate water sharing, both surface and groundwater, at river basin, national and international levels, to ensure that quality and quantity are not jeopardized.
- Government commitment, institutional frameworks, good monitoring and strong enforcement will be needed to turn policies into practice.
LAND, SOIL AND DRAINAGE

There are now only a few areas of the world where large tracts of suitable new land can be developed using available water. The rate at which new land is being developed for irrigation is now barely keeping pace with land going out of production. The reasons include: rapid expansion of cities and industrial enterprises; over-population and degradation of marginal lands by humans and livestock; waterlogging and salinity caused by over-irrigation and seepage/leakage from canals.

For many soils, the remedies for waterlogging are well-known, though expensive: drainage, better water use at farm level, and effective canal lining. Certain soils, like heavy clays and acid sulphate soils (coastal SE Asia), present particular problems. Cost-effective techniques for drainage and reclamation of such soils need to be developed.

Drainage systems throughout the world are performing poorly, often through poor maintenance. Returns on investment are not being achieved. Drainage maintenance is frequently accorded a low priority because the consequences of failure are not quantified or understood.

The returns to effective drainage are perceived to be large, but quantitative information on the actual benefits, in improved crop yields and the environment, are lacking for both arid and humid regions. There are virtually no data linking crop yield with flooding/waterlogging, though some information is available linking yield with the salinity of irrigation water.

Brackish water with an undesirably high chloride content, and sewage effluent are both being increasingly used in agriculture. There are big uncertainties about the long-term effects on the soils, especially when low quality water is used in techniques such as sub-irrigation in arid/semi-arid zones. Careful research is being carried out in a number of countries, but pressure imposed by water shortage in other regions means that unsustainable practices are being adopted.

Many low-income countries suffer increasingly from poor soil fertility as marginal lands are exploited. The situation is aggravated by low use of fertilizer, particularly in sub-Saharan Africa, where the average application of about 14 kg per hectare compares with 200 kg in East Asia. Past and current failures to replenish soil nutrients in many countries can only be rectified by balanced and effective use of organic and inorganic plant nutrients, and through improved soil management practices. Appropriate actions include the following:

- Research and development are still needed to find cost-effective and practical methods for large-scale reclamation of problem soils, including heavy clays. Promising techniques need to be tested in practice and disseminated.
- Documented studies of the impacts on land of changes in local water budgets need to be undertaken, the results interpreted, and disseminated. Verified regional groundwater and salinity models are needed to help examine strategic options for development.
- There are major unknowns concerning the long-term effects on soils of using water of different qualities, including effluents, particularly in techniques like sub-irrigation.
- Research already undertaken on the impacts on soil of using poor quality waters needs to be extended. Existing results should be widely disseminated to engineers and agricultural extension agencies.
- Detailed investigations and analyses of the returns to investments in drainage, and the immediate and long-term implications of alternative technologies and strategies, are needed.
- There is very little documented information about the response of crops to waterlogging and flooding.
- Irrigation and drainage design and management need to be integrated more closely. There is potential for improvement in productivity and savings in water.
- Formalized procedures for diagnosing and improving drainage performance are needed.
- Deteriorating marginal lands need to be stabilized, others need to be rehabilitated. Suitable crops need to be developed and appropriate techniques need to be disseminated.

Institutional, Economic, and Social Issues

Poor sustainability - lack of finance

On small irrigation schemes, particularly in Africa, farmers often lack the support of irrigation agronomists, access to inputs, and to markets. The support they may receive is often not well-informed about irrigation.

Governments increasingly wish to improve the performance of the irrigated agriculture sector, whilst simultaneously devolving responsibilities for O&M to farmers. The two objectives may be in conflict. Policies such as turnover depend for success on active adaptation by the irrigation authority to a new service role, which is ill-defined. In many countries,
procedures to target available maintenance funds in the most effective way are lacking. Improved maintenance practices are also needed.

The financial disciplines applied to domestic and industrial water users have been widely ignored in irrigation. In many developing countries, the recovery rate of irrigation charges has been falling for decades. The real value of charges has also fallen so that recoveries commonly only cover a small fraction of actual O&M expenditure.

Realistic tariffs, possibly based on a graded set of charges and subsidized, if necessary, by government, should cover at least the costs of O&M. Without a substantial income and new institutional arrangements, O&M will remain under-funded, systems will continue to disintegrate prematurely, and international institutions will still be requested to finance rehabilitation projects at regular intervals. Financial autonomy and accountability to users are key needs.

Water prices have fallen in real terms in many countries over recent decades. In some countries, water is still considered to be free, but fees can be introduced to cover the costs of providing the supply. On many schemes, the rate of fee collection is poor. Current policies to raise charges are often linked to Participatory Irrigation Management (PIM), under which farmers are required to accept greater responsibilities for O&M. Although the policy is considered successful in countries such as Mexico and Turkey, there are still question marks about its general application to schemes in Asia, where low-value cereals are grown. Actions needed include:

- The determinants of success of improved small-scale irrigation need to be understood and disseminated for wider replication, taking account of cultural differences.
- Initiatives by NGOs, and others, to develop irrigation packages suited to small farmers, including improved irrigation, agronomy, credit, technical support and assistance with marketing, need to be extended, to make improved practices more widely acceptable on a permanent basis.
- Studies are needed to determine the most effective and appropriate institutional structure to deliver improved supply and system maintenance. Without assurance of better supply, and faced with increased costs, farmers have little incentive to embrace PIM.
- Despite a number of initiatives, better procedures to identify priority rehabilitation works, based on return to investment, as well as on social equity, are needed.

- Similarly, limited maintenance funds need to be targeted to areas where they will have most effect. Improved maintenance methods are also needed.
- More needs to be known about the issues involved in developing workable demand-management strategies on large public irrigation schemes in Asia.
- Studies of farmers' ability to pay need to include realistic estimates of the maintenance costs required to sustain systems under a range of conditions.
- Experience from organizations around the world should be acquired and disseminated, to provide information and guidance on water pricing and the conditions under which water markets can be effective.

**Situation of the poor**

Currently more than 1.3 thousand million people are absolutely poor, with incomes of a dollar a day, or less, per head. A further 2 thousand million are only marginally better off. Increasing numbers are destitute as a result of civil strife, enforced migration, or the impacts of natural disasters. Despite positive projections for economic growth in the developing world, disparities in income levels and growth, both within and between countries, are likely to persist unless policies to help the poor are developed. The effects of the last GATT Round were predicted to be positive for all continents except Africa. Considering that Africa is most in need of help, the prospects for small farmers are potentially very serious.

Rights to surface water are largely taken up. The rural poor, who are often landless, have very limited access to water for even the most basic human needs. They are unable to improve their lot by growing food, yet much of the food available in the market is too costly to buy despite the fact that world food prices are at historic lows. Proposals that nations should meet their food deficits by importing more will not help those who are already disadvantaged. Studies are needed to determine how best to help the rural poor help themselves in a rapidly-changing world, for example through positive policies towards marginal farmers in peri-urban areas.

A stable rural sector is of prime concern to developing governments, some already grappling with problems caused by overcrowded cities. Protective policies instituted by national governments to provide safeguards to the livelihoods of small farmers are likely to be increasingly outlawed under rulings by the World Trade Organization.
The peri-urban area plays a vital role in supplying the food requirements of growing cities. According to Cornish and Aidoo (2000), some 11,500 ha. of informal irrigation is undertaken around Kumasi, Ghana, almost twice the “formal” irrigated area for the whole of Ghana. Farmers are constrained by factors which depend on location e.g. water, credit, marketing. There are also implications for human health and the environment of using low quality waters. Proposed actions are presented below:

**Environment**

Most of the problems resulting from point source pollution are well-understood. Strong legislation, improved institutions, adequate resources and campaigns of education are needed to make a serious impact on the problems. Policies such as “the polluter pays” may be appropriate in some cultures. Improved monitoring and strong regulation are needed.

The greater part of the budget allocated to scheme maintenance is commonly spent on clearing sediment and/or weeds from the distribution system. In severe cases, the annual maintenance budget is insufficient to clean the whole system, so that the water delivery performance progressively deteriorates. High concentrations of nutrients from use of excess fertilizer use are dramatically increasing weed problems. Toxic blue-green algae are a problem in some countries. The levels of pesticides in waters also used for domestic purposes are generally completely unknown. Obstructed channels and small storage reservoirs also provide good breeding grounds for diseases such as schistosomiasis (Africa) and malaria. Research by Chimbari and Bolton (1991,1993) in Zimbabwe indicated that technical measures, included as part of an integrated health programme, can reduce the incidence of disease. The work needs to be applied elsewhere.

There is extensive experience around the world in catchment stabilization techniques. Methods to estimate siltation in canal systems (Lawrence et al. 1998), and in reservoirs (Atkinson, 1996), have been developed. However, available techniques need to be disseminated more widely to professionals. Government institutions and community groups need to be strengthened/restructured to undertake effective preventative measures.

Problems of erosion of marginal lands and desertification are being addressed by a number of research organizations and development groups, but the outcomes are still not widely available to the irrigation community. The participation of land users is essential to success.
Waterlogging and salinity problems caused by canal leakage are covered under Land, Soil and Drainage.

A number of countries are facing major problems in disposing of saline drainage waters. One solution proposed for countries where land is not limiting is to create drainage “sinks”. Full analysis of the long-term implications of such proposals is overdue. The following actions are proposed:

- There is an urgent need to find cost-effective measures to reduce the growth of weeds. ‘Environmental’ techniques used in river maintenance work in industrialized countries might be adaptable to the developing world.
- Existing knowledge and techniques for minimizing adverse effects of irrigation on the environment and human health need to be made more freely available to developing countries.
- Crop varieties requiring lower doses of fertilizer and pesticides, under development by traditional breeding techniques and bioengineering, are urgently needed.
- Existing techniques for reducing erosion of lands and siltation in systems need to be disseminated.
- New and cost-effective means for treating polluted land are needed.
- Disposal of poor quality drainwater is an increasing problem, particularly in arid/semi-arid areas. The long-term impacts of solutions like the establishment of “sink” areas, are, as yet, unquantified and need monitoring.
Setting priorities for research

Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications. R&D is a term covering three activities: basic research, applied research and experimental development. Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective. Experimental development is systematic work, drawing on existing knowledge gained from research and/or practical experience, that is directed to producing new materials, products or devices, to installing new processes, system and services, or to improving substantially those already produced or installed. (Second chapter of the OECD 1993 Frascati Manual – Reference: ISBN 9264 1 44029)

**Methodology**

Unlike industrial development projects, it is not realistic to try to select priorities for research by economic methodologies setting benefits against expected returns. There are frequently a number of causes contributing to a problem, some of them interlinked. It is then not possible to assign a benefit uniquely to a research initiative, unless all constraints are simultaneously removed. In the present analysis, the following aspects have been considered in assigning research issues to categories of priority:

- estimates of the ‘importance’ of the issue in terms of its impact on agriculture and other water users, and of the immediacy of need for action
- estimates of the scale or extent of the issue
- has a need been identified in previous analyses?
- has a need been identified by a country or countries?
- the possible socio-economic impact if the research findings were successfully implemented, assuming other possible constraints were also removed

The research issues included in Table 1 have been based on the identification process in Chapter 2, where topics have been grouped under broad headings such as “Water quality” or “Land, soil, drainage”. Because problems usually have a number of causes, the research issues in the Table in general embrace more than one topic, from one or more of the groups in Chapter 2.

The **significance** of the various research issues has been assessed in terms labelled: **Critical**, **Urgent** or **Important**, which have been defined as follows:

- **Critical** Issue imminently or actually affecting economies, food security, and, potentially, also political stability.
- **Urgent** Issue will affect economies and food security in the near future
- **Important** Issue will affect national economies and food security in the medium to longer term

The **Scale** of an issue, or in crude terms, the numbers of persons likely to be affected by the problem, is defined in two categories: **Global** and **Regional**. The intention has been to ensure that problems affecting a region or nation are not underrated. Viewed in global terms, an issue might seem to have lesser weight, whereas in regional terms it might be of huge significance.

The issues have been assigned to categories as follows:

- **Category A**. **Critical – Global Relevance**
- **Category B**. **Critical - Regional Relevance**
- **Category C**. **Urgent – Global Relevance**
- **Category D**. **Urgent - Regional Relevance**
- **Category E**. **Important – Global Relevance**
- **Category F**. **Important – Regional Relevance**

As implied by the labelling, **Critical** issues are considered to be of the highest priority, followed by **Urgent** and **Important** ones. There is no particular ordering to the topics within the categories.

Column 3 in the Table shows whether an issue was identified during one or more IPTRID missions and/or by previous analyses of research need. It is noted that IPTRID missions were directed to certain
areas of research, and to certain countries. The fact that a particular issue was not identified by missions therefore does not necessarily indicate that the issue was not of concern to countries.

Column 4 identifies other spheres of interest which need to be involved and/or actions which need to be taken to secure the best outcome to the research work.

Almost by definition, any issue identified as a ‘Gap’ in research will not have received much attention from irrigating nations or researchers generally. In the present analysis, a number of Gaps have been identified: they are not new issues, but they are issues which hitherto been considered to fall outside the focus of irrigation research. They are really gaps between disciplines, which have not been adequately addressed to date by any single discipline. They have become important in the light of real concerns for growing problems of water scarcity and the realisation that the different water sectors can no longer plan in isolation. Provided such issues have real weight, absence of expressed demand for research should not by itself be sufficient to discount a need. Gaps have been noted in Column 5 of the Table.

### TABLE 1
Summary of research issues

<table>
<thead>
<tr>
<th></th>
<th>1 Ref.</th>
<th>2 Research Issue</th>
<th>3 Identified by</th>
<th>4 Accompanying parallel actions needed</th>
<th>5 Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Country Missions</td>
<td>Analysis of needs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category A</td>
<td>Critical Issues – Global Relevance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CG1</td>
<td>Sustainable methods to improve water use efficiencies on small farms develop packages of measures including improved technologies, such as micro-irrigation. Costs.</td>
<td>Yes</td>
<td>Yes</td>
<td>Support: private sector; credit; improved agriculture. Extension markets.</td>
<td>Experiences from sustainable systems and determinants of success need to be wisely disseminated.</td>
</tr>
<tr>
<td>CG2</td>
<td>Improve system management: investigate service-orientated institutions for O&amp;M; performance benchmarking; improved techniques. Costs.</td>
<td>Yes</td>
<td>Yes</td>
<td>Institutional change. Political decision.</td>
<td>Co-operation with e.g. IWMI to characterise systems for improvement.</td>
</tr>
<tr>
<td>CG3</td>
<td>Reduce losses in conveyance: cost-effective methods to restore defective linings; pipelines for simple operation at lower levels of system. Costs.</td>
<td>Yes</td>
<td>Yes</td>
<td>Involve private sector.</td>
<td>Private sector to investigate potential for new methods. Evaluate effect on groundwater users of reduced recharge.</td>
</tr>
<tr>
<td>CG4</td>
<td>Demand management strategies, including water pricing.</td>
<td>No</td>
<td>Yes</td>
<td>Political decision. Institutional change. Co-operate with IWMI, IFPRI.</td>
<td>GAP. Disseminate examples to promote informed debate on the issues.</td>
</tr>
<tr>
<td>CG5</td>
<td>Develop crops: more output per drop and/or increased resistance and/or reduced inputs or for marginal soils. Crop breeding and biotechnology.</td>
<td>No</td>
<td>Yes</td>
<td>Private sector. Cooperation with CGIAR. Dissemination.</td>
<td>Crops must suit small farmers in the developing world. Engineers need to understand characteristics so as to save water.</td>
</tr>
<tr>
<td>CG6</td>
<td>Document viable strategies to deal with water scarcity. Categorise world-wide experience.</td>
<td>No</td>
<td>Yes</td>
<td>Dissemination.</td>
<td>GAP. Disseminate examples to promote informed debate.</td>
</tr>
<tr>
<td>CG7</td>
<td>Groundwater, water-sharing: pilot schemes to serve different water use sectors; shared aquifers below international boundaries.</td>
<td>No</td>
<td>No</td>
<td>Monitoring. Institutions and policies. Cooperation: IWMI, hydro-geological surveys.</td>
<td>GAP. Some initiatives underway with international backing. Information and lessons need to be disseminated urgently. Formal monitoring systems widely needed.</td>
</tr>
<tr>
<td>CG8</td>
<td>Mechanisms for reallocation water; knowledge, policies, institutional issues.</td>
<td>No</td>
<td>No</td>
<td>Political decision. Institutions. Monitoring.</td>
<td>GAP. Disseminate examples to promote informed debate.</td>
</tr>
<tr>
<td>Category B</td>
<td>Critical Issues – Regional Relevance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CR1</td>
<td>Small-scale irrigation: participatory processes and appropriate design to improve sustainability.</td>
<td>Yes</td>
<td>Yes</td>
<td>Support: private sector; credit. Improved agriculture. Extension; markets.</td>
<td>Particularly important to Africa. Experiences from sustainable systems and the determinants of success need to be widely disseminated.</td>
</tr>
<tr>
<td>CR2</td>
<td>Stabilize marginal soils. Participatory process and appropriate design to improve sustainability.</td>
<td>Yes</td>
<td>Yes</td>
<td>Training farmers, extension officers. Dissemination.</td>
<td>Could be combined with research into improved use of rainfall (above). Action research with NGOs, CGIAR etc. Disseminate best practises.</td>
</tr>
<tr>
<td>CR3</td>
<td>Reuse of wastewater and mixing waters: predictive techniques and sustainable strategies. Pollution transmission mechanisms. Rehabilitation of degraded aquifers.</td>
<td>Yes</td>
<td>Yes</td>
<td>Training farmers. Co-operation with other water users. Monitoring soil/water.</td>
<td>Experience to date needs to be disseminated to guide work in new areas.</td>
</tr>
<tr>
<td>CR4</td>
<td>Disposal of drainwater. Document alternatives which have been implemented with real environmental, technical socio-economic costs.</td>
<td>Yes</td>
<td>Yes</td>
<td>Dissemination. Environmental monitoring.</td>
<td>Real information needed on the full consequences of different strategies.</td>
</tr>
</tbody>
</table>

**Category C  Urgent Topics – Global Relevance**

| UG1 | Improved methods of identifying priority rehabilitation and maintenance works according to impact on performance. | Yes | Yes | Institutional change. Farmer participation. | Urgent needs to sustain policies of turnover. See also Irrigation Management. |
| UG2 | Impacts of globalisation on small farmers. | No | Yes | Dissemination | GAP. In Africa, globalisation is predicted to have negative effects. Elsewhere, small farmers will have difficulty competing, without support. Investigation urgently needed. |
| UG3 | Rural water development planned to reduce women’s tasks and improve sustainability. | No | Yes | Promote co-operation with WS. Disseminate. | Particularly in Africa, women are principal agents in domestics and agricultural water use. Better integration would improve rural efficiency. |
| UG5 | Low-cost ways, incl. biotechnology, for cleaning polluted land and water. Treatment of water at source or point of use. | No | Yes | Private sector involvement. Dissemination. | Technologies being pioneered in the West have to be affordable in the developing world. |

**Category D  Urgent Issues – Regional Relevance**

| UR1 | Improved cost-effective desalination technologies. | No | No | Private sector. Co-operation with specialist centres. | GAP. Particularly important to coastal areas of Middle East to meet potable and industrial demand. Dissemination of improved technologies to planners. |
| UR2 | Procedures for problem diagnosis, identifying priority works and sustaining drain performance cost-effectively. | Yes | Yes | Farmers’ participation. | Existing experience needs to be collated and disseminated. |
| UR3 | Measures to reduce catchment erosion and siltation in water systems. | Yes | Yes | Farmers’ participation. Dissemination. | Effective techniques are available but they need to be disseminated. |
| UR4 | Cost-effective ways to reclaim problem soils where land is constraining factor. Saline, sodic, saline-sodic and acid sulphate soils. | Yes | Yes | Training farmers, extension officers. Dissemination. | Results of more recent work need to be widely disseminated. Details and costs of reclamation to be made available to the profession. |

**Category E  Important Issues – Global Relevance**

| IG1 | Effects of climate change on water resources and crop demand. | No | No | Co-ordination with climate specialists. Dissemination. | GAP. Small adverse changes can have disproportionate effects, since irrigation is the major water user and involves high losses. |
| IG3 | Impact of irrigation on lives of the poor, national economy, environmental and water resources. | No | No | Co-ordination with development workers. Dissemination. | GAP. Irrigation perceived to benefit the rich. Holistic studies needed to demonstrate to funders the full benefits to people and nations. |
| IG4 | Peri-urban agriculture. Research to introduce packaged improvement, including training. | No | No | Support: private sector; credit; improved agricultural extension; markets. | GAP. Peri-urban agriculture provides a high proportion of urban food, but is unrecognized by governments, suffers constraints and involves health risks. |
**Priorities**

**Critical Global** (*CG 1-8*) issues in Table 1 are all connected with the need to improve the use of water. Some are inter-related.

The first five items (*CG 1-5*) are alternative, or complementary, strategies to save water. Planners need better information on costs and the implications of the different approaches, as implied by the gap issue “Document viable strategies to deal with Water Scarcity” (*CG6*). It is not expected that IPTRID will deal directly with issues of crop variety development (*CG5*), but it could have an important role in disseminating information to the profession, providing it with a realistic view of the state of the art and its potential. For this purpose, co-operation could be sought with, for example, CGIAR centres.

Similarly, gap issues *CG 7, 8* (Groundwater and Water Reallocations) are not areas where IPTRID has particular strengths, but it is essential that irrigation planners and managers are well-informed, so that they can actively engage in seeking solutions. IPTRID could disseminate essential information if it could draw upon the strengths of organisations like national Geological Surveys, IWMI and IFPRI.

**Critical Regional** (*CR 1-4*) issues have been identified in previous analyses but much work remains, in particular to disseminate successful strategies and to identify determinants of success and failure. Successful small-scale irrigation (*CR1*) and stabilisation of marginal soils (*CR2*) are particularly crucial for Africa. Effective reuse of water (*CR3*) and disposal of drainwater (*CR4*) are vital, e.g. for Pakistan and Egypt.

**Urgent Global** (*UG 1-5*) issues include: improved identification of priority rehabilitation and maintenance works (*UG1*), which is particularly significant as O&M resources are reduced and systems are turned over to farmers; impact of globalisation on small farmers, particularly in Africa (*UG2*), a gap issue; integration of water supply and irrigation development in rural areas to improve women’s livelihoods and sustain developments (*UG3*); improved rainwater harvesting to support dry land agriculture and reduce demand for irrigation water (*UG4*); low cost ways of treating polluted land (*UG5*).

**Urgent Regional** (*UR 1-4*) issues have been identified in previous work, except for desalination. *UR1*: desalination in coastal arid areas is unlikely to benefit agriculture directly, but cost-effective technologies should help meet urban and industrial demand and so reduce competition with agriculture. Specialist knowledge is required, but the issues and potential of the technologies could be disseminated by IPTRID. *UR2*: methods to diagnose problems and sustain the performance of drains, involving farmers, are needed. *UR3*: much is known about how to reduce catchment erosion and techniques for predicting and designing against sediment deposition in water systems. The information needs to be disseminated to the profession. *UR4* deals with reclamation of problem soils. Some advances have been made: the work needs extending and details of promising techniques disseminated.

**Important Global** issues (*IG 1-7*). *IG1*, Climate change, (gap issue) is increasingly relevant. Recent studies suggest that impacts will now occur earlier
than the second decade of the millennium, the timing previously predicted. It becomes increasingly important to include probable negative effects in water planning. IG2: Global water quality will decline as demand and effluent loads increase. Future actions will need to be based on trends in pollution. It is therefore important to establish baseline water quality figures, a target which is only feasible on a wide scale if monitoring methods are quick and relatively cheap. More appropriate methods are becoming available. The profile of water quality monitoring needs raising and methodologies described. IG3 (gap issue): international funding agencies are reducing funding for irrigation. The role of irrigation in providing food security, employment for a high proportion of developing country populations, including the poor, and in stabilising rural populations, needs to be documented to help inform national and international policies. IG4 (gap issue): peri-urban agriculture is increasingly recognised as an essential contributor to urban food supplies. Assistance is needed to improve practices, remove constraints and reduce health risks.

IG5: weed growth in canals and drains. There is a risk that condition of systems will worsen under turnover. Alternative maintenance methods need to be tested. IG6: adverse environmental effects of irrigation. Results of integrated action research need to be disseminated. IG7: planners and their projects would benefit from basic guidance in social development issues.

**Important Regional issues (IR 1-3).** IR1: standard pump sets available in the marketplace are relatively cheap but they often operate ineffectively. Investigation of whole-life costs is needed. IR2: technologies for conversion of solar energy are predicted to improve markedly. Solar pumping for irrigation is still not generally an attractive option. Potential needs to be factored into future water and energy planning. IR3: drainage policies would be guided by knowledge of the true economics of drainage using basic information of crop response to waterlogging and flooding.

**Field Manuals.** Dissemination has been a recurrent theme in many of the issues identified above. Manuals for field staff in local languages are particularly needed for many of the subject areas, including improved water management and maintenance.
Setting priorities for research
Conclusions and recommendations

Many research issues and topics in irrigation and drainage have been identified over the years by researchers, and also during IPTRID country missions. They are summarized in Chapter 2 and Appendixes I and II. In many cases, relevant research work is being undertaken, somewhere in the world. However, given the pressing need to increase the agricultural output per unit of water, more resources and/or better international cooperation may be needed to turn the findings of research into workable procedures, techniques and tools to solve problems in the field. Research gaps exist principally at the interfaces between sectors, for example irrigation and water-supply, or irrigation and agriculture, where neither discipline has hitherto taken responsibility for finding solutions.

Outstanding research issues identified in the review have been allocated to one of six categories, on the basis of their Significance (Critical, Urgent, Important) and Scale (Global, Regional), in Table 1. Viewed in global terms, some issues might seem to have lesser weight, whereas in regional terms they could be of huge significance. The aim has been to try to ensure that problems affecting a region or nation are not under-rated.

**Water quantity.** The over-riding question for the majority of developing nations is how irrigated agriculture is to reduce its high share of the overall water resource. The possible areas for achieving better use of the resource include: reducing conveyance losses; improving system management; improving water use efficiency at field level; introducing demand management; developing crops with lesser water demands. The mix of solutions will vary from nation to nation, but there is currently little assistance to help planners select appropriate policies, because firm data on the likely returns to individual strategies are not available (Critical-Global issues). Strategies and mechanisms for dealing with water scarcity and for reallocating the available resource between sectors are needed. (Critical-Global issues). Critical-Regional issues are: Strategies to reuse and/or mix waters, and Improved performance of small-scale irrigation. Improved use of rainfall in drylands is rated an Urgent-Global issue. Development of more cost-effective desalination methods (dissemination needed) will help to meet urban needs in some areas and so reduce the pressures on the resource. (Urgent-Regional issue). Climate change (Important-Global issue) will adversely affect the available resource in many areas, so must enter the planning process as soon as possible. Energy issues (Important–Regional) are energy-efficient small pumps sets and Improved solar conversion technologies, issues which could be linked together in arid climates, where IPTRID could help by disseminating state-of-the-art information.

**Groundwater development.** (Critical-Global. Gap issue). There are severe concerns about the uncontrolled exploitation of groundwater. There is no general co-ordination between different water sectors. Furthermore, good data upon which systems of control and regulation could be based, are frequently lacking. Currently, no single body seems to be focussed on these issues. IPTRID should highlight the need for field research, since agriculture is the biggest user of the resource and has the most to lose. Working pilot models for the sustainable development of groundwater are urgently needed. Sound policies require good information from field monitoring, and good predictions derived from modelling. There is an urgent need to promote, coordinate and disseminate research on the issues.

**Water quality.** There are major unknowns concerning the mechanisms involved in non-point source pollution, to which agriculture is the biggest contributor, and the long-term impacts of reusing wastewater and sewage sludge on soils and aquifers in different climates. Better knowledge and predictive techniques are needed to guide water reuse, mixing strategies and aquifer rehabilitation. (Critical-Regional). The development of appropriate management strategies depends on better knowledge of the processes involved. Baseline studies of water quality, using low cost monitoring techniques, are needed (Important-Global).

**Sharing the resource** (Gap issues). As water becomes increasingly scarce, close cooperation between water user sectors will become essential. The mechanisms for water-sharing and reallocation currently do not exist (Urgent-Global issues). As the major water user with a rural constituency, irrigation will increasingly take the brunt of pressure to reduce water use. Irrigation professionals will therefore need to take a lead in setting up co-operative
forums for sharing water with other sectors. Good information on water usage and potential, which can only come from research, will be needed. Working models are needed to guide water sharing between:

- urban water supply, rural water supply, industry and agriculture, particularly in peri-urban areas
- irrigation and drainage
- irrigation, aquaculture and wetlands

**Land, soil and drainage.** Research to stabilise marginal lands, involving NGOs, and, e.g., CGIAR, with the participation of farmers. (Critical-Regional issue). Cost-effective techniques are needed to reclaim problem soils. (Urgent-Regional). Provide authoritative data on the short- and long-term implications of options for disposing of drainwater. Problem diagnosis procedures for cost-effective and sustained drain performance (Urgent-Regional) and information on crop response and economic returns to drainage (Important-Regional) are needed.

**Institutional, economic and social.** Potential improvements to system operation and maintenance are severely limited by funding and institutional factors. Research from organizations around the world should be collated to draw conclusions about: institutional arrangements to achieve technically efficient and financially viable O&M; successful introduction of realistic water pricing; water markets. Better procedures to identify priority rehabilitation and maintenance works are needed (Urgent-Global). The impacts of globalisation on smallholder agriculture (Urgent-Global) and of irrigation on securing poor livelihoods (Important-Global) need to be known, to guide policies. Better information on the constraints to, and possible health hazards of, peri-urban agriculture is needed to guide development policies (Important-Global). Planners and their projects, would benefit from basic guidance on social issues like land tenure, conflict resolution, participatory processes (Important-Regional).

**Environment.** Disposal of drainwater (Critical-Regional). Authoritative information, including costs, is needed on the consequences of different strategies. Low-cost ways of treating polluted land and water, possibly based on biotechnology, are needed (Urgent-Global). Effective techniques to reduce catchment erosion and siltation in water systems need to be disseminated (Urgent-Regional). Knowledge and formalized procedures for minimising adverse effects of irrigation on the environment and on human health are also lacking (Important-Global). Environmental measures to control weed growth in canals and drains should be tested (Important-Global).

**Dissemination.** In virtually all the topics outlined above, up-to-date information on issues and progress would be of great help to researchers, but more particularly to those in professional practice. In addition, manuals for field staff in local languages are needed for many subject areas, including improved water management and maintenance.

**Recommendations**

1. IPTRID’s primary focus is on research to produce solutions to technical problems in irrigation and drainage, but quantitative improvements in the field sometimes cannot be achieved without removing institutional, financial, social or other constraints. In promoting research, it is suggested that IPTRID make efforts to identify possible external constraints to success. Efforts could then be made to get the host nation and funding agency (if any) to investigate whether such constraints could be removed, to improve the chances of success.

2. Pilot-scale trials of methods and techniques represent a valid strategy for testing concepts under field conditions. IPTRID might choose to promote more work of this type.

3. As water becomes increasingly scarce, irrigation professionals need to extend their vision beyond the traditional domain of the irrigation sector. IPTRID can potentially play a very valuable role in disseminating state-of-the-art information from other sectors and disciplines including water supply, agriculture, geohydrology, and other water users. Knowledge of relevant work in other sectors can help the profession to make informed decisions about reducing water use, increasing output and minimising environmental damage. Issues such as: improved crop varieties, proper tillage, mulching, rainwater harvesting, energy efficiency in pumping, requirements for sustained development, could add value to the immediate focus on technical aspects of irrigation and drainage. In its dissemination, IPTRID could consider including articles or issues papers by organizations hitherto not involved.

4. There are certain areas, such as: solar power for low-head pumping, improved desalination technologies, bio-treatments for waste waters and polluted soils or genetic engineering of appropriate crops, where applied research has to be followed by extensive commercial development, to arrive at economically viable
product packages and solutions for development problems. All of them offer great potential to the water sector and thus, directly or indirectly, to irrigation, but they are beyond the immediate research remit of IPTRID. However, the irrigating world will greatly benefit by early dissemination of the results when the technologies mature.

Finally, it is hoped that although this Review is primarily intended as a guideline for IPTRID, others involved in research and developments in irrigation and drainage may find it useful when drawing up plans and programmes for future research.
Review of research and development needs in irrigation and drainage

Bibliography

KEY REFERENCES (IN CHRONOLOGICAL ORDER)


20 IPTRID. Review of country activities. IPTRID Secretariat, FAO, Rome, Italy. (1999)

OTHER REFERENCES (IN ALPHABETICAL ORDER)


