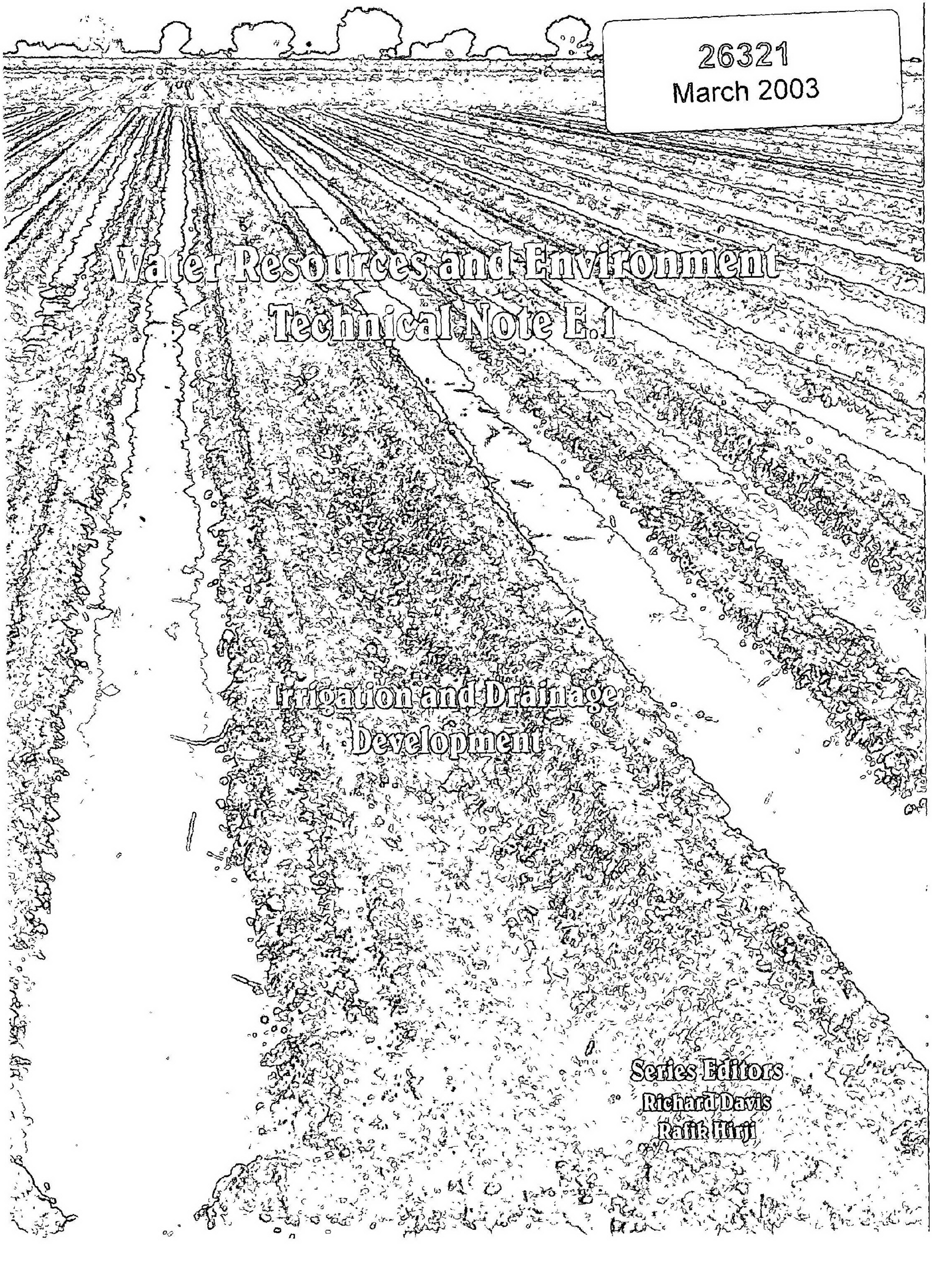
Public Disclosure Authorized
Public Disclosure Authorized

26321
March 2003



Water Resources and Environment
Technical Note E.1

Irrigation and Drainage Development

Series Editors
Richard Davis
Rafik Hirji

WATER RESOURCES AND ENVIRONMENT

TECHNICAL NOTE E.1

Irrigation and Drainage: Development

SERIES EDITORS
RICHARD DAVIS, RAFIK HIRJI

The World Bank
Washington, D C

Water Resources and Environment Technical Notes

Copyright © 2003
The International Bank for Reconstruction and Development/THE WORLD BANK
1818 H Street, N.W., Washington, D.C. 20433, U.S.A.

All rights reserved.

Manufactured in the United States of America
First printing March 2003

CONTENTS

Authors
Walter Ochs and
Hervé Plusquellec

Technical Adviser
Stephen Lintner

Editor
Robert Livernash

Production Staff
Cover Design Cathe Fadel

Design and Production
The Word Express, Inc

Notes
Unless otherwise stated,
all dollars = U.S. dollars
All tons are metric tons

Cover photo by
UNESCO
Irrigation fields, Mexico

This series also is available on the
World Bank website
(www.worldbank.org)

Boxes

Figures

Tables

FOREWORD

The environmentally sustainable development and management of water resources is a critical and complex issue for both rich and poor countries. It is technically challenging and often entails difficult trade-offs among social, economic, and political considerations. Typically, the environment is treated as a marginal issue when it is actually key to sustainable water management.

According to the World Bank's recently approved Water Resources Sector Strategy, "the environment is a special 'water-using sector' in that most environmental concerns are a central part of overall water resources management, and not just a part of a distinct water-using sector" (World Bank 2003: 28). Being integral to overall water resources management, the environment is "voiceless" when other water using sectors have distinct voices. As a consequence, representatives of these other water using sectors need to be fully aware of the importance of environmental aspects of water resources management for the development of their sectoral interests.

For us in the World Bank, water resources management–including the development of surface and groundwater resources for urban, rural, agriculture, energy, mining, and industrial uses, as well as the protection of surface and groundwater sources, pollution control, watershed management, control of water weeds, and restoration of degraded ecosystems such as lakes and wetlands–is an important element of our lending, supporting one of the essential building blocks for sustaining livelihoods and for social and economic development in general. Prior to 1993, environmental considerations of such investments were addressed reactively and primarily through the Bank's safeguard policies. The 1993 Water Resources Management Policy Paper broadened the development focus to include the protection and management of water resources in an environmentally sustainable, socially acceptable, and economically efficient manner as an emerging priority in Bank lending. Many lessons have been learned, and these have contributed to changing attitudes and practices in World Bank operations.

Water resources management is also a critical development issue because of its many links to poverty reduction, including health, agricultural productivity, industrial and energy development, and sustainable growth in downstream communities. But strategies to reduce poverty should not lead to further degradation of water resources or ecological services. Finding a balance between these objectives is an important aspect of the Bank's interest in sustainable development. The 2001 Environment Strategy underscores the linkages among water resources management, environmental sustainability, and poverty, and shows how the 2003 Water Resources Sector Strategy's call for using water as a vehicle for increasing growth and reducing poverty can be carried out in a socially and environmentally responsible manner.

Over the past few decades, many nations have been subjected to the ravages of either droughts or floods. Unsustainable land and water use practices have contributed to the degradation of the water resources base and are undermining the primary investments in water supply, energy and irrigation infrastructure, often also contributing to loss of biodiversity. In response, new policy and institutional reforms are being developed to ensure responsible and sustainable practices are put in place, and new predictive and forecasting techniques are being developed that can help to reduce the impacts and manage the consequences of such events. The Environment and Water Resources Sector Strategies make it clear that water must be treated as a resource that spans multiple uses in a river basin, particularly to maintain sufficient flows of sufficient quality at the appropriate times to offset upstream abstraction and pollution and sustain the downstream social, ecological, and hydrological functions of watersheds and wetlands.

With the support of the Government of the Netherlands, the Environment Department has prepared an initial series of Water Resources and Environment Technical Notes to improve the knowledge base about applying environmental management principles to water resources management. The Technical Note series supports the implementation of the World Bank 1993 Water Resources Management Policy, 2001 Environment Strategy, and 2003 Water Resources Sector Strategy, as well as the implementation of the Bank's safeguard policies. The Notes are also consistent with the Millennium Development Goal objectives related to environmental sustainability of water resources.

The Notes are intended for use by those without specific training in water resources management such as technical specialists, policymakers and managers working on water sector related investments within the Bank; practitioners from bilateral, multilateral, and nongovernmental organizations; and public and private sector specialists interested in environmentally sustainable water resources management. These people may have been trained as environmental, municipal, water resources, irrigation, power, or mining engineers; or as economists, lawyers, sociologists, natural resources specialists, urban planners, environmental planners, or ecologists.

The Notes are in eight categories: environmental issues and lessons; institutional and regulatory issues; environmental flow assessment; water quality management; irrigation and drainage; water conservation (demand management); waterbody management; and selected topics. The series may be expanded in the future to include other relevant categories or topics. Not all topics will be of interest to all specialists. Some will find the review of past environmental practices in the water sector useful for learning and improving their performance; others may find their suggestions for further, more detailed information to be valuable; while still others will find them useful as a reference on emerging topics such as environmental flow assessment, environmental regulations for private water utilities, inter-basin water transfers and climate variability and climate change. The latter topics are likely to be of increasing importance as the World Bank implements its environment and water resources sector strategies and supports the next generation of water resources and environmental policy and institutional reforms.

Kristalina Georgieva
Director
Environment Department

ACKNOWLEDGMENTS

The Bank is deeply grateful to the Government of the Netherlands for financing the production of this Technical Note.

Technical Note E.1 was drafted by Walter Ochs and Hervé Plusquellec, building on the earlier work by Jan Hoevenaars and Roel Slootweg of Geoplan of the Netherlands. It was reviewed by Safwat Abdel-Dayem and Doug Olson of the World Bank. Helpful comments were also received from Ashok Subramanian of the World Bank.

INTRODUCTION

An estimated 270 million hectares of irrigated land–about 18 percent of the world's cropland–generates about 40 percent of the world's food production.[1] Among regions, there are great disparities in the distribution of irrigated land and its contribution to food security. Around 65 percent of the world's irrigated lands are in Asia, while Africa and South America have less than 5 percent each. Compared to other water uses, irrigation is a high volume, low quality, low cost use. Given the large demands placed on water resources by irrigation, the extent of irrigation development has major implications for other water uses, including water needs for cities, industries, and hydropower, as well as for national parks, wetlands, instream uses, and estuaries.

Globally, about 150 to 200 million hectares are drained, including 100 to 150 million hectares of rainfed land and approximately 50 million hectares of irrigated land. This land contributes 10 to15 percent to global food production (Smedema 2002). Drainage developments generally are intended to improve agricultural productivity, but can have significant environmental effects, including both benefits–such as control of salinization and waterlogging–and costs–such as reduction in water quality for downstream uses.

The global irrigated area increased by more than 2 percent a year in the 1960s and 1970s, slowing down to 1.6 percent in the 1980s. The area under irrigation is currently increasing at an annual rate of about 1.4 percent, largely because of a considerable slowdown in new investment combined with the loss of some irrigated lands as a result of salinization and urban encroachment. India and China accounted for about two-thirds of the global expansion during the 1990-98 period.

The area irrigated by groundwater has been growing at an exceptional rate in recent decades because of greater certainty of supply, advances in technology and, in many instances, government subsidies for power and pump installation. At present, about 175 million hectares are irrigated by surface water, and about 95 million hectares are irrigated by groundwater. The increasing use of groundwater has led to the overexploitation of groundwater resources in some arid and semiarid regions, where water tables are falling at an alarming rate–often 1 to 3 meters a year. The point has been reached in some areas where the exploitation of groundwater is posing a major threat to the environment, health, and food security. For example, about 10 percent of the world's agricultural food production depends on mined groundwater, or water that is extracted faster than it is replenished.

Consequently, proper use of water for irrigation and drainage (I&D) is essential for sustainable water resources management. This Technical Note is one of three dealing with irrigation and drainage. Technical Note E.2 deals with issues arising from the rehabilitation of existing I&D systems. Technical Note F.2 discusses issues, concepts, techniques and methods involving water conservation for I&D schemes. This Note contains six sections. The first two discuss the reasons for irrigation and drainage and irrigation water quality issues. The following sections review potential environmental consequences and solutions related to irrigation and drainage, methods for quantifying impacts of irrigation, and drainage and remedial programs. The Note concludes with two case studies.

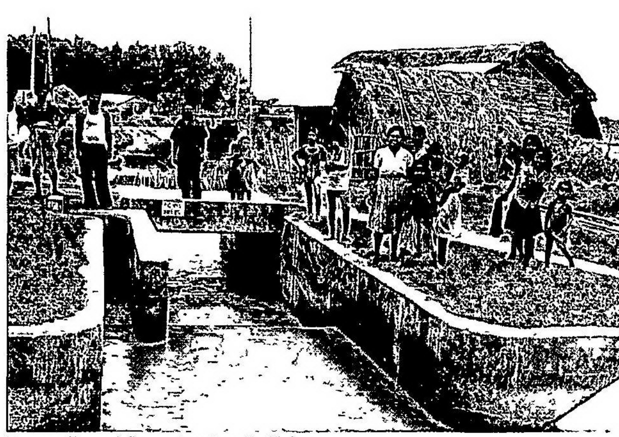


Photo by Herve Plusquellec, World Bank

Proportional flow divider, Pakistan

[1] Schultz, B. (2001).

WHY IRRIGATE OR DRAIN LAND?

IMPROVE AGRICULTURAL PRODUCTIVITY AND SUSTAINABILITY

The primary reason for irrigating and draining land is to improve or sustain agricultural productivity in areas where surface soils are naturally dryer or wetter than desired. Semiarid regions often have higher agricultural productivity if irrigated, while naturally wet regions are often habitable at a higher density, accessible with less effort, or have higher agricultural productivity when drained. The sustainability of these I&D systems, however, is questionable if a sound operation and maintenance (O&M) program is not carried out or if poor irrigation practices are used by the farmers and operators of the system. Poor irrigation and agronomic practices have led to salinity, sodicity, and waterlogging, which affect 40 to 50 percent of the 270 million hectares of land currently under irrigation.[2] Systems that do not have proper and continuous O&M programs eventually require extensive rehabilitation due to reduced system performance over time (Note E.2). Over-abstraction of water for irrigation has also degrated entire ecosystems and created conflicts with downstream uses. Other reasons for system modernization or rehabilitation include upgrades in technology to improve services and efficiency, or because environmental consequences need to be addressed.

The explosive increase in the use of groundwater for irrigation is largely because groundwater offers greater certainty in the supply of water than surface sources of water. On average, agricultural yields in groundwater-dependent irrigation areas in India are 30 to 50 percent higher than yields in areas irrigated from surface sources. With an adequate and assured water supply from groundwater (whether the supplemental or primary supply source), farmers are more confident in making investments in items such as fertilizers, pesticides, and improved crop varieties, leading to higher yields (although there can also be increasing pollution from excessive use of agricultural chemicals).

MAKE RURAL AREAS MORE HABITABLE

Irrigation and drainage systems can improve the habitability of rural areas through:

- Improved domestic water supply, which is often associated with irrigation water supply
- Reduction of mosquito breeding areas to help reduce malaria and other diseases normally associated with drainage systems
- Reduction, through drainage, in salt crusts which can become windblown
- Extension of drainage into villages to provide improved storm water control and better foundation strength for buildings.

These factors can be important because of the improved living conditions they bring to the rural community.

IMPROVE ACCESSIBILITY

Rural areas in the developing world often have poor transportation facilities for marketing agricultural and other products, for accessing larger cities for health care and social experiences, and for educational opportunities. The development, expansion, or improvement of I&D areas often provides opportunities to improve accessibility and contributes to the improvement of other rural infrastructure such as energy, health, and communications.

Canals and drains sometimes provide the opportunity for parallel roads to be built without taking much additional land out of production, thus reducing the destruction of wetlands or lakes. However, these developments have to be planned and executed carefully to ensure that environmental degradation, such as drainage of wetlands and shallow lakes, does not occur–and if it occurs, that it is minimized or mitigated

[2] Szabolcs, I. (1994).

POTENTIAL ENVIRONMENTAL BENEFITS RELATED TO IRRIGATION AND DRAINAGE

Social and economic improvements are the key reasons for irrigation and drainage, but with careful planning other benefits can often be realized. In Case Study 1, for example, water saved through conservation efforts was allocated to a downstream green corridor. The control of waterlogging and salinization for agricultural productivity reasons can also benefit the environment. With water table management and water level control in open drains, eutrophication can be mitigated by removing excess nitrogen through denitrification.

Deciding how to balance these on-site and off-site benefits with the costs to the I&D districts involves policy decisions that need to be taken by each country in the light of its own development needs. For example, establishing high water quality standards for the discharge of drainage waters will lead to downstream environmental benefits. The decision on whether these benefits are great enough to warrant the costs to the irrigators is a social decision taken by each country. Sometimes countries will elect to establish national water quality standards that apply equally to all I&D schemes; other times they will use a case-by-case approach to establishing discharge standards (see Notes D.1 and D.2).

WATER QUALITY ISSUES

WATER QUALITY REQUIREMENTS FOR IRRIGATION WATER

Arid and semiarid climates. Salinity is the key water quality parameter of concern for irrigation water. This is almost always a problem in arid and semiarid regions. Salinity problems develop if salt accumulates in the crop root zone to a concentration that causes yield loss. If allowed to accumulate excessively, it can cause complete salinization and elimination of all vegetative cover. FAO guidelines indicating the degree of plant growth restriction are given in Table 1.

Another key item related to water quality for irrigation is the sodium adsorption ratio (SAR), which describes the tendency for sodium ions to be adsorbed onto soil particles in preference to other

TABLE 1.
DEGREES OF RESTRICTION FROM SALINITY AND SAR FOR IRRIGATION USES OF WATER

	Potential Restriction		
	None	Slight / Moderate	Severe
Salinity			
Electrical Conductivity (dS/m)	< 0.7	0.7 to 3.0	> 3.0
Total Dissolved Solids (mg/l)	< 450	450 to 2000	> 2000
SAR			
0–3	$EC_w > 0.7$	EC_w 0.7 to 0.2	$EC_w < 0.2$
3–6	$EC_w > 1.2$	EC_w 1.2 to 0.3	$EC_w < 0.3$
6–12	$EC_w > 1.9$	EC_w 1.9 to 0.5	$EC_w < 0.5$
12–20	$EC_w > 2.9$	EC_w 2.9 to 1.3	$EC_w < 1.3$
20–40	$EC_w > 5.0$	EC_w 5.0 to 2.9	$EC_w < 2.9$

Source FAO, 1985

ions (particularly calcium and magnesium). At any given SAR, infiltration rates increase as water salinity (measured as electrical conductivity, EC_w) increases. Thus SAR, together with the salinity of the applied water, gives an estimate of potential infiltration problems (Table 1).

If treated wastewater is to be used for irrigation (see Note F.3), tests should also be run for pathogens, heavy metals and nitrate (NO_3). Excessive nutrients (NO_3-N >30 mg/l) and bicarbonate (HCO_3 > 8.5 me/l)[3] often reduce crop yield or quality through unsightly deposits on fruit or foliage and can cause corrosion of equipment. If there is appreciable runoff, high nutrient levels can also lead to eutrophication of surface water bodies and nitrate contamination of groundwaters.

Humid, temperate, and tropical climates. Water quality for irrigation is normally not a great concern in humid, temperate, and tropical climatic areas. When irrigation is used in these areas, it is often on the more porous soils and as supplemental irrigation, particularly when high-value crops are grown. Tropical areas are sometimes irrigated because of extensive dry periods during each year. Irrigation extends the growing season and provides an opportunity to grow crops that cannot be grown during wet seasons. Water quality is often poor during these dry periods in surface waters, but groundwater quality is normally better, especially if it is taken from deeper aquifers.

WATER POLLUTANTS RELATED TO IRRIGATION AND DRAINAGE SYSTEMS

Both surface and subsurface drainage effluents contain substances that are potential pollutants, which may be purposely introduced into the irrigation water, mobilized by the practice of irrigation and/or drainage, or concentrated as a result of evapotranspiration.

The pollutants include salts, nutrients, pesticides, trace elements, sediments, pathogens, acids and elevated temperatures. The processes causing these pollutants to be released and methods for managing them are described in the next two sections.

IRRIGATION: ENVIRONMENTAL CONSEQUENCES AND SOLUTIONS

TECHNICAL PROBLEMS AND SOLUTIONS

Environmental problems caused by irrigation can be avoided or considerably mitigated by proper planning, design and operation of irrigation projects. Waterlogging and salinity are caused by over-irrigation and by not constructing drainage works before the problem is evident. Water losses from canals, reservoirs, and on farmland are often underestimated because of unrealistic expectations about the efficiency of these phases of an irrigation system, including the long-term effectiveness of measures such as canal lining using rigid materials (see Note F.2).

Good design requires a sound understanding of the relationship between design, construction, operation, and performance of irrigation and drainage systems, both on- and off-farm. Some government and donor-supported projects do not address these issues adequately because of a lack of expertise in modern design.

It is important to note that the effective implementation of modern policy approaches to irrigation requires the appropriate physical environment. Only a combination of appropriate physical infrastructure, proper policy instruments, adequate institutional capacity, and committed management (including enforcement of regulations) will lead to high performance of irrigation systems.

[3] Reported in milliequivalent per liter (me/l) (mg/l / equivalent weight = me/l)

WATERLOGGING OF SOILS

Waterlogging occurs when soil pores fill with water because the soils either have few interstitial spaces (low porosity) or do not drain well (poor hydraulic conductivity or presence of impervious layers), thus reducing the air content. Oxygen deficiency results and carbon dioxide accumulates to toxic levels. This directly impairs root growth and the ability to absorb nutrients for most crops except rice, which can transfer air through its stomata to its roots. Consequently, rice and wetland vegetation are able to grow well when the roots are submerged for long periods.

As a result of poor irrigation practice, waterlogging problems occur on about 50 million hectares of irrigated land. High water tables can develop in areas where excess water is applied, leading to waterlogging a considerable distance from the source areas. Farmers in the low parts of a command area are vulnerable if farmers on the higher parts do not carry out good irrigation water management practices. Waterlogging also occurs along irrigation supply canals and downstream from reservoirs.

Waterlogging problems need to be addressed at their source. Improving irrigation water management (on-farm and off-farm) is a priority. Control of sources of seepage water from canals and reservoirs is also important (Note F.2). In many cases, these actions will not be able to cure waterlogging quickly or completely enough. Although drainage is the usual solution to removing excess water, excess groundwater can also be removed through bio-drainage, i.e. transpiration by vegetation. Bio-drainage has not been used extensively in large-scale projects, but has promise if used under the right conditions. The transpiration capacity of the landscape is enhanced by introducing high-water-use vegetative types in large enough areas to maintain groundwater balances below the root zone of the crops or vegetation that is to be protected.[4] Figure 1 illustrates the bio-drainage concept.

SALINIZATION OF SOILS

Soil salinization, illustrated in Figure 2, is a concern in irrigation projects located in most arid climates, some semi-arid climates and in a few project areas in temperate or tropical climates that are close to oceans or salt water tidal areas. In these climates, salt can accumulate in the soil and groundwaters and be brought up to the root zone of crops as

[4] FAO (2002).

FIGURE 1.
FLOW TOWARD DEPRESSED GROUNDWATER TABLE UNDER PLANTATIONS

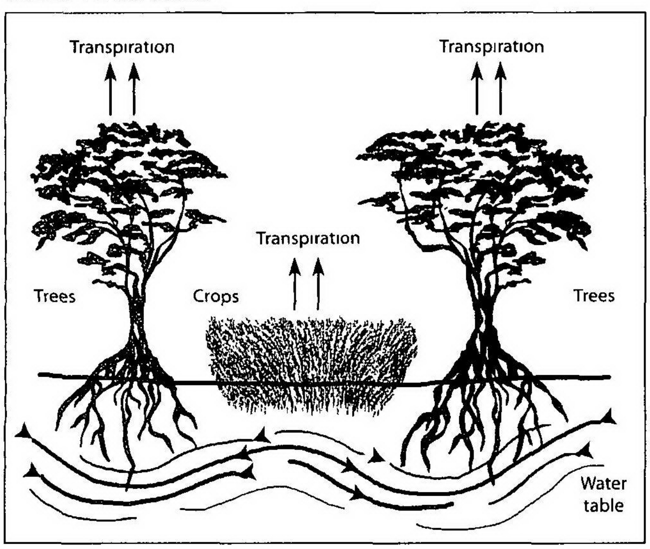
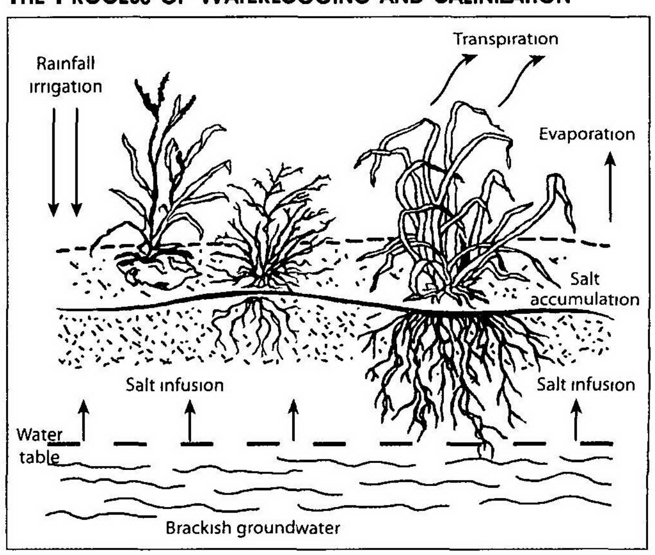


FIGURE 2.
THE PROCESS OF WATERLOGGING AND SALINIZATION



BOX 1.
EYGPT'S NILE DELTA

Agriculture in Egypt depends almost entirely on irrigation from the Nile River. With the year-round availability of water, two or three crops a year can be grown. Under the present cropping pattern, the quantity of irrigation water applied to a representative area in the southern part of the Nile Delta is about 1,240 mm/year. Although the irrigation water has low salinity (0.3 dS/m), it brings salts into the soils at a rate of 8.0 tons/ha/year. Egypt has had great success in controlling this salinity.

Until the Aswan High Dam was constructed in the 1960s, the Nile flooded every August and September, causing natural leaching of the salts from lands in the delta area. Salinity increases were evident soon after the frequency of natural floods dropped following the completion of the dam. Salinity and waterlogging are considerably more serious in the northern part of the delta since that area is further downstream and the close proximity of the agricultural lands to the Mediterranean Sea causes a shallow watertable. Six subsurface drainage pilot projects were installed between 1961 and 1969. The results showed that this drainage has reclaimed the salt-affected soils and maintained a high level of productivity.

The Government of Egypt, in partnership with the World Bank, has invested about $3 billion since the 1970s to provide drainage systems to 2 million hectares. The program is expected to continue until the irrigated area (about 2.7 million hectares) is fully covered by the year 2017. Both the government and farmers have shown great commitment to the program by adopting appropriate technologies, improving the irrigation system, transferring management to water user associations, and adopting a well functioning system of cost recovery There has been a remarkable 230 percent increase in crop intensity, and the yield of crops in Egypt stands now among the highest in the world, especially for wheat, rice, and cotton. Improved drainage accounts for 15 to 25 percent of the yield increase. Reuse of drainage water has contributed to an overall water use efficiency that is one of the highest in the world.

Source: ILRI 1994; Safwat Abdel-Dayem, 2000, World Bank Drainage Portfolio Review, internal document

groundwater tables rise with excessive water applications. In extreme cases, the salts can accumulate on the surface forming salt scalds. In most temperate and tropical climates, salts have been leached from soil profiles over time and salinity is not a problem. When an irrigation and drainage area is developed in many arid climates and some semi-arid climates, often soils must be artificially leached before cropping can begin. In these climates, it may take 4 to 8 years before sufficient salt is leached for the soils to be used productively.

About 23 percent of the world's cultivated land has saline soils and another 37 percent has sodic soils.[5] Sodic soil is closely related to saline soils. The application of irrigation water to areas with abundant salts and more than 15 percent exchangeable sodium leads to the formation of sodic soils (sometimes called alkaline soils). If soil has a low chloride and calcium content, or if irrigation water has abundant exchangeable sodium bicarbonate or sodium carbonate, the clay particles in the soil adsorb the sodium and magnesium salts and swell. The soil loses its permeability, which hinders the ability of water to infiltrate into the soil. Plant roots and soil organisms may be starved of oxygen. Adding gypsum is the common solution to sodic soil problems.

Irrigation water also contains a mixture of salts from the catchment area of the water supply or the recharge area of an aquifer. In coastal areas, overexploitation of groundwater resources can lead to saltwater intrusion and consequent increases in the salinity of irrigation water. The extent to which these salts accumulate in the soil will depend upon the irrigation water quality, irrigation management, and the adequacy of drainage.[6] Land salinization initially is noticeable as a reduction in crop yields or vegetative growth. It can gradually progress to a complete sterilization of the landscape if management interventions such as drainage are not applied to leach excessive salts from the soil. Box 1 describes the management of salinization problems in the Nile Delta in Egypt.

[5] Szabolcs, I. (1989).
[6] FAO (1985).

Soil salinization can cause environmental problems that have direct economic impacts. Not only will crop productivity decline, but soil biodiversity, wetlands, and areas of natural vegetation such as tree belts will all be affected.

USE OF TREATED WASTEWATER

Wastewater from municipalities is increasingly used for irrigation (Note F.3). This reuse benefits both municipal sources and irrigation by reducing the quantity of wastewater discharges to waterways as well as providing water, nutrients, and organic matter to irrigation areas. In arid and semi-arid climates, wastewater irrigation may significantly increase farm production. At a flow of 140 liters per capita per day, 100,000 people would generate about 5 million cubic meters of wastewater per year, enough to irrigate about 1,000 ha, using efficient irrigation methods. Irrigation of parks and green-space with wastewater is becoming increasingly attractive to improve the environment in and around municipalities. Irrigation of grasslands and forestlands or windbreaks can be used to develop greenbelts to control desertification and for reforestation as well as erosion control. The ability to generate income from the wastewater stream improves the efficiency of investments in wastewater treatment and contributes to the conservation of freshwater sources.

However, the reuse of wastewater can be limited by inadequate water resources legislation and an inability to control effluent quality. For example, wastewater can be unsuitable when it contains significant loads of industrial effluent. The effect of wastewater irrigation on public health is the primary concern, although there are also significant environmental risks through oxygen depletion caused by the breakdown of organic contaminants and the introduction of toxic chemicals into susceptible ecosystems. Adequate pathogen removal can be achieved with a low-cost, multicell waste-stabilization pond system with about 20 days of detention. Monitoring and evaluation of systems involving wastewater use are critical, and care must be taken to promptly correct developing deficiencies before they become serious problems.

HABITAT LOSS

Water-source areas include the catchment area for water supply, surface water stored in reservoirs behind dams, and sometimes in-stream storage. There can be significant habitat losses in all these areas during irrigation development projects. In these cases, World Bank policies require environmental assessments prior to development, as well as monitoring during and after project implementation. Deforestation in particular can cause serious problems in and below the catchment areas. Soil conservation practices should be undertaken in catchment areas to minimize downstream sedimentation problems. Habitat loss can be kept to a minimum in the catchment if proper environmental planning is included in the soil conservation plans. Habitat losses and changes are often significant during the development of water storage and transmission facilities. Reservoirs inundate extensive areas and create a habitat that is difficult to manage for fisheries if the changes in water depth are too fast or severe.

Habitat changes will also take place within the irrigation command area and the area receiving drainage waters. These habitat changes may not be great if an existing system is being restored or modernized (see Notes E.2 and F.2). If the I&D system is being significantly expanded or a new system is being developed, there are likely to be major changes in habitat values, including the loss of wetlands. Sound environmental assessments are critical in these situations; mitigation needs to be undertaken if there are significant impacts on important habitat.

Both water quantity and quality (see next section) can be affected downstream of an I&D development. Fisheries, wetlands, estuaries and, in cases like the Aral Sea (Box 2), even air quality can all be adversely affected. Water flows will inevitably be reduced downstream of an irrigation scheme because of the increased transpiration from crops and canal vegetation and evaporation from fallow areas and possibly drainage from water disposal basins. Additionally, the downstream flow hydrograph will be affected by the timing of releases from upstream reservoirs to irrigation areas. In extreme cases, the flow regime can be reversed with maximum flows occurring dur-

BOX 2.
THE ARAL SEA

The problems in the Aral Sea region were caused by the rapid expansion of irrigated agriculture in the Amu Darya and Syr Darya River basins. The waters of these rivers were diverted from reaching the Aral Sea with the result that its surface level dropped by 17 meters over 40 years, and its surface area was reduced from 66,000 km^2 to less than half that size today. Disposal of polluted drainage water back to the rivers triggered adverse water quality and environmental problems for downstream populations. Major inter-basin diversions were planned from rivers flowing to the Arctic Ocean to limit the expected shrinking of the Aral Sea, but were not carried out due to environmental, political, and financial concerns.

The drying out of the Sea has not only seriously affected the livelihoods of those previously dependent on the resources of this major water body but has severely reduced the extent of adjacent wetlands. Dust storms are now a common feature of this area, as winds transport the soils of the now dry lakebed long distances. In addition, wind blown salts from irrigation-induced salinity pose a health hazard to rural populations.

ing the crop-growing season (late spring-summer) after the development of an irrigation scheme instead of, say, during winter-spring. Triggers for fish and waterbird migration and breeding, plant habitat, and floodplain regeneration will all be affected, impacting downstream communities who are dependent on these resources (see Note C.1)

INCREASED DISEASE TRANSMISSION

Irrigation systems can provide habitat for the vectors transmitting water-related diseases such as schistosomiasis (Box 3), malaria, encephalitis, and dengue fever (mosquitos).

The type of water preferred by mosquitoes for egg-laying varies between species, but the following conditions are generally suitable:

- Edges of reservoirs and rivers, shallow pools with emergent vegetation
- Small pools of ponded water, as in ungraded road ditches
- Stagnant drains or watercourses
- Paddy rice fields, if control measures such as stocking larvivorous fish are not used.

Irrigation project areas can provide these sets of conditions. Planners, designers, operators, and maintenance staff need to be aware of these habitat

BOX 3.
FAVORABLE HABITAT FOR AQUATIC SNAILS

Schistosomiasis, also known as bilharziasis, is a parasitic disease that leads to chronic ill health. Despite efforts to control this disease, caused by flatworms that reside in the bloodstream, it is estimated that 200 million people, mainly in rural areas, are infected. The majority of these cases occur in Africa.

Individuals are infected when they come into contact with water containing the worms, which can penetrate through skin within seconds. Using freshwater snails as a host, the larvae of the worms go through several cycles. The snails eventually produce thousands of new parasites, which are then excreted by the snail into the surrounding water.

Irrigation canals provide excellent habitat for these snails. The conditions that favor them include:

Moderate light penetration	Water velocity < 0.3 m/s
Little turbidity	Gradient < 0.2m/km
Partial shade	Temperature 0-37°C
Slight pollution with excreta	Optimal temperature 18-28°C
Firm mud substrata	Aquatic weeds in excess
Gradual change in water levels	

Source: Birley, M. H. (1989).

factors and develop drainage designs that minimize these conditions. Disease monitoring and response programs should be developed in susceptible areas. These programs are usually carried out on a community or regional basis. The Further Information section contains references to documents on the management of these diseases.

SOIL LOSS BY WATER AND WIND EROSION

Soil loss by both water and wind erosion can be a significant issue in both the catchment area and in the command area of I&D schemes, primarily because of the removal of the natural vegetation cover. Erosion from catchment areas can seriously impact both the natural habitat of upland species and the productivity of upland croplands. Water erosion is less likely within the command area because of the generally flatter terrain. However, there can be local erosion due to poor irrigation practices on-farm, leading to sedimentation problems within the fields or in tail-water recovery systems and open drains. These sediment accumulations impose excessive maintenance costs, cause deterioration of wildlife habitat, result in breeding areas for disease-causing vectors, and interfere with efficient crop production. Sediment can also be deposited at downstream locations, where the water velocity slows. Many of the environmental problems caused by siltation have economic dimensions, such as loss of reservoir capacity or depth of channels, loss of bird nesting or fish spawning locations, or stimulation of algae growth or other ecological imbalances in canals (see Note G.4).

Project areas with surface soils lacking cohesion, such as sandy soil, are susceptible to wind erosion. This can become a serious issue when long and flat open stretches are exposed to prevailing winds. Barriers such as tree belts planted perpendicular to prevailing winds are necessary in these project areas. In desert environments, green belts comprising trees, shrubs, and grasses often need to be developed to serve as a buffer between the desert environment and the I&D scheme. In China's Tarim Basin II Project (see Note F.2), green belts were established using drainage water. These green belts were found to improve habitat value in the desert environment.

DRAINAGE: ENVIRONMENTAL CONSEQUENCES AND SOLUTIONS

Drainage in relation to agricultural and irrigation interests is the removal of excess surface and subsurface water from land, including removal of soluble salts from the soil to enhance crop growth. At farm level it is an environmental mitigation measure for the waterlogging and salinization problems associated with some irrigation schemes. While the purpose of drainage schemes is to enhance the productive and environmental capacity of irrigation areas, the disposal of the drainage water can impose significant environmental impacts on off-site and downstream areas.

LEACHING OF NATURAL SOIL ELEMENTS

Numerous natural soil elements and compounds can be leached from soil profiles during irrigation and enter drainage systems. Salt (NaCl) is the most commonly leached compound that can degrade water quality if disposed of in freshwater systems. Some metals and metalloids, such as arsenic (As), lead (Pb), and selenium (Se), are toxic when present in sufficient concentrations and pose a threat to agriculture, aquatic flora and fauna, and human health. Toxic concentrations can arise from their collection in drainage waters as well as a result of evaporation in ponds or wetlands. Even if water concentrations are low, the elements can bioaccumulate in the food chain. Selenium pollution of the Kesterson National Wildlife Refuge in California was perhaps the most famous case of damage from naturally occurring ions (Box 4). Box 5 provides a summary of lessons learned from a successful drainage project to reclaim sodic lands in Uttar Pradesh, India.

Box 4.
Damage from drainage: Kesterson National Wildlife Refuge, California (USA)

In 1982, scientists found that selenium concentrations were increasing in the ponds of the Kesterson National Wildlife Refuge, the temporary terminal point in the drainage system for a large block of agricultural land in the San Joaquin Valley. Plans called for the ponds to eventually drain to the San Francisco Bay Delta and Pacific Ocean, but other funding priorities, environmental concerns, and other process delays caused the drainage system to remain incomplete. It is still incomplete.

Selenium and other potentially harmful, naturally occurring elements such as arsenic and molybdenum were being leached from soil and bedrock in upstream-irrigated areas and transported to the reservoir, where they were accumulating. Thousands of waterfowl and fish died outright from these contaminants, while others produced young that had severe birth defects. The concentrations of these substances at the pond inlet were probably not high enough to cause these problems. However, the concentrations were increased by evaporation in the closed ponds.

Eventually, drainage from the Westlands Irrigation District and other contaminated sources was closed by court order. A $100 million case for compensation of farmers is still under consideration. The National Research Council eventually concluded that drainage system design must not only account for salt accumulation in soil and salt disposal in downstream water bodies, but also for potentially toxic effects of trace elements that may leach from soil and rock underlying the irrigated lands.

Sources: Skaggs, R. et al. 1994, National Research Council. 1989. *Irrigation-Induced Water Quality Problems* Washington, D.C.: National Academy Press.

Once they occur, these problems with toxic trace elements are difficult to manage. Areas proposed for new or expanded irrigation schemes should be checked for their presence. If these elements are present in nuisance concentrations, then water application rates should be designed to minimize drainage and hence reduce the risk of leaching into drainage waters.

LEACHING OF APPLIED MATERIALS SUCH AS FERTILIZERS AND PESTICIDES

The two primary nutrients in drainage water are nitrogen and phosphorus, both of which contribute to eutrophication of surface waters (Note G.4). If these nutrients are present in high concentrations,

Box 5.
The Uttar Pradesh Sodic Lands Reclamation Project, India

Poorly managed irrigation of inherently sodic soils in Uttar Pradesh has rendered 1.25 million ha barren because of sodicity. Uttar Pradesh's weather, which alternates between heavy monsoons and prolonged dry periods, makes sodification worse. Where drainage is blocked, either naturally or by roads or canals, surface water accumulates and evaporates, leaving behind sodium ions, which form an electrochemical bond with clay particles in the soils, creating toxic salts.

The World Bank funded a project in 1993 to help solve this problem. By tackling environmental protection, land tenure and improved agricultural production, the project was able to provide an integrated and sustainable solution to a complex situation. Extensive farmer participation was essential. The farmers took the major decisions and did virtually all the work. Smallholders were helped to gain clear title to land; this was critical in providing the motivation for technical improvements. The technical improvements involved soil testing, digging surface drainage, building tubewells, applying gypsum, leaching and flushing with good quality groundwater, good crop husbandry, and regular flushing of salts from link drains.

An area of 68,400 ha of sodic land (152 percent of the SAR) was reclaimed and 36,000 ha of barren land was brought under green cover for the first time. There was a significant increase in cropping intensity because of the successful land reclamation. Evaluations indicated that all objectives were met and the re-estimated economic rate of return was 28 percent against the appraisal estimate of 23 percent.

Source: Agriculture & Rural Development Project Profiles, World Bank.

they can fuel algal blooms in either drainage channels or downstream waterways, which leads to deoxygenation of the water, the release of toxins into the water, and the physical blocking of water off-takes. Nitrogen in surface drainage flow is predominantly ammonium, since it is readily adsorbed on clay particles. The nitrate form is found in subsurface drainage flow, since this form is very soluble. Phosphorus can be found in drainage water in both organic and inorganic forms. Little phosphorus is found in subsurface drainage water because of its strong adsorption to clay soil particles as it leaches through the soil.

Most pesticides are synthetic organic compounds. Surface runoff, in particular, can carry pesticides that cause toxicity problems in aquatic organisms (such as invertebrates) in downstream areas. This can adversely affect higher levels of the food chain. High pesticide concentrations in subsurface drainage water are less likely because of the filtering action of finer textured soils present in most irrigation schemes, although pesticides such as atrazine have been discovered in some groundwater systems.

The relative emphasis on surface and subsurface drainage in the conceptual design can have significant environmental implications, and should be carefully evaluated in any new construction, as well as expansion or rehabilitation work on existing I&D schemes. Although there are techniques to trap nutrients and pesticides before they enter downstream waterbodies, it is most cost efficient to control them at the source. This means that farmers should be educated in the most effective application rates; perverse incentives such as subsidies should not exist to encourage their use; and methods for transporting nutrients and pesticides via both water and eroded soils should be minimized. The introduction of integrated pest management programs and the possible adoption of genetically engineered crop varieties in the future are likely to lead to reduced use of pesticides.

OFF-FARM PROBLEMS

Most hydraulic and hydrologic problems downstream from irrigation and drainage projects are avoidable if the drainage system is properly designed and maintained. Sources of water in drainage systems include:

- Surface flows in excess of crop needs or due to excessive rainfall collected by surface drains
- Seepage water from canals or reservoirs collected by surface or subsurface drains
- Flows from subsurface drains that control waterlogging and salinity in the crop root zone
- Base flows from open drains and streams within the project area that intersect a high water table
- Leaching water from deeper surface and subsurface drains.

Hydraulic problems are often caused by sediment and excessive weed growth that reduces flow capacity by clogging channels. These conditions also place significant demands on maintenance operations such as dredging and cleaning of the outlet channels. Off-site impacts from dredged sediments, and other materials such as accumulated vegetation, are a strategic environmental issue. Dredging itself can release pollutants into the water such as phosphorus. Improper disposal of dredged materials is also a concern because pollutants may leach from the dumped material into surface or groundwater. Ideally, the dredged material should be used in construction related to rehabilitation or modern-

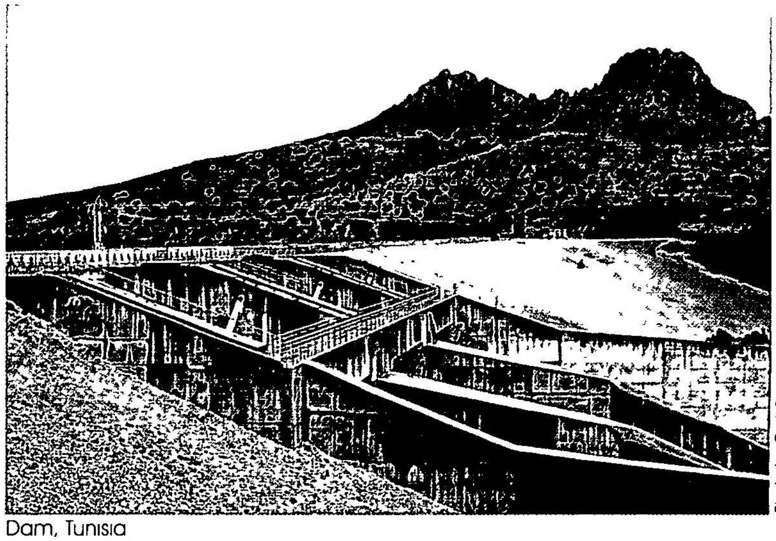


Photo by Curt Carnemark, World Bank

Dam, Tunisia

ization needs in the project. This option can be identified through a strategic environmental assessment early in the project cycle. However, this is not always feasible, and the dredged material must be disposed of with full regard to its possible impacts.

Hydrologic problems downstream are related to the effect of drainage water on river flows and the timing of peaks and troughs. Low flows are a particular problem because concentrations of pollutants are considerably higher during these periods. Hydrologic basin-wide studies are important to ascertain the impact of discharges (quantity, peak drainage flows, and the time of the peak flow) from a specific project area on the flows of the basin. Drainage flows can affect the proper ecological functioning of downstream river reaches, floodplains, wetlands, and estuaries in the same way that upstream abstractions for irrigation can affect the flow regime of a river.

WATER QUALITY PROBLEMS

Surface and subsurface drainage effluent contain substances that are potential pollutants. These pollutants may be:

- Purposely introduced into irrigation or drainage water
- Mobilized by the practice of irrigation and/or drainage
- Concentrated as a result of evapotranspiration (ET).

Common downstream water quality contaminants include sediments, salts, pesticides, pathogens, heavy metals and increases in water temperature.

Erosion and sediment transport problems are common with open drains used to remove surface water runoff. Coarser sediments eroded from irrigation areas and channels are subject to rapid deposition in the slower flowing reaches of rivers or outlet channel systems, blanketing habitat as well as causing hydraulic problems. Finer sediments will be carried through to downstream bodies of water, where they will cause physical problems such as blanketing of in-stream habitat and changes in river flow. In addition, sediments (particularly colloidal sediments) can block light penetration into the water, thus affecting the productivity of food chains. Benthic fauna and flora will be particularly affected. Other problems can arise from the pollutants (primarily nutrients and pesticides) attached to the sediments.

Drainage waters that contain salts can affect aquatic biota and human uses of the water, particularly drinking water. Being a solute, salt is very difficult to remove once it has entered drainage waters, so it is important to manage water applications to minimize salt mobilization and drainage of saline waters in these environments. This may require a change in the technology used in the I&D scheme. For example, in Pakistan, it was found that many of the drainage tubewells mobilized excessive salts because they leached too deep in the soil profile. During preparation of the National Drainage Program, a decision was made to correct some problem areas by changing the drainage system to horizontal pipe subsurface drainage, which would mobilize less salt.

Surface flows can pick up pathogens from villages, animal yards, and septic fields, creating health hazards to downstream users of the water. Canals and main open drainage systems often receive partially treated or untreated industrial wastewater from urban and heavily populated rural areas. Designers need to anticipate the possibility of pathogen and heavy metal contamination from increased population densities from new or expanded I&D schemes. Minimization of runoff and proper containment of surface flows together with enforcement of standards for disposal of polluted wastewaters will reduce this problem.

It is common for water temperatures to increase below shallow reservoirs–as well as within irrigation and drainage systems–because of exposure to the sun. While elevated drainage water temperatures are unlikely to affect downstream aquatic life in tropical and many sub-tropical areas, they can cause problems in cold-water streams or those supporting anadromous fisheries.

WATER QUALITY MONITORING

Water quality monitoring should be included in the design of all drainage systems. Points where drainage water should be monitored vary with each system, but in general the following locations should receive consideration:

- The ultimate disposal point for drainage water from the entire project area to ensure that downstream water quality requirements are met (see Note D.1)
- Upstream and downstream from any waste water treatment system to monitor the performance of the treatment facilities and to facilitate operational or management changes
- At the ends of major drains in the system to determine if excessive loads of pollutants are being contributed by specific parts of the system
- At specific locations where there is the potential for point-source pollution such as below industries, villages, and animal lots
- Upstream of any off-take point for drainage water reuse, particularly when mixed with canal water.

SPECIAL CONSIDERATIONS

There are a number of special issues that can arise with drainage development projects. The following paragraphs provide an introduction to these issues and their solutions. More details can be obtained from the references in Further Information.

Organic soils. Peat and muck are two common terms often associated with organic soils. Subsidence of the land surface is an irreversible result of draining organic soil. The subsidence is caused by oxidation as water is removed. The rate of oxidation is related to the depth of the water table and the temperature. The oxidation rate is lower if a high water table is maintained and in cooler climates. In spite of the problem of subsidence, organic soils can be very productive, and in humid climates are often used for growing high-value crops such as vegetables and flowers. Such I&D schemes can be sustainable if the level of the water table is maintained.

Water table management systems. These are also being used in humid climates (particularly in Eastern Canada and the United States) to help reduce the concentration of chemicals (primarily nutrients and pesticides) in agricultural drainage water by minimizing runoff. Since pesticides usually attach to soil particles, the reduction of surface runoff from fields reduces the transportation of pesticides to the drainage waters.

Acidification. Rich tropical coastal wetland environments are sometimes severely damaged by improper reclamation of soils containing pyrite. These soils are usually called acid sulfate soils. When drainage systems are deep, subsoil layers are exposed to air and become oxidized. This leads to the formation of sulfuric acid from the pyrites. The pH levels in water draining from these areas can drop below 3, seriously harming plant and animal life, including the death of mangroves and fish kills. Iron and aluminum can also be mobilized from soils when pH levels drop, causing human health problems if the downstream water is used for drinking purposes. Maintaining a high water table to prevent the pyrite from oxidizing will control this problem. Box 6 describes two examples of problems with acid sulfate soils.

Reuse of drainage water. Downstream users inevitably reuse irrigation drainage water in an unplanned way because these waters find their way to watercourses through surface and sub-surface pathways. However, the planned reuse of drainage water is increasingly being introduced in water scarce regions through constructed water reuse schemes. Because pollutants tend to become more concentrated as water is reused, water quality monitoring and adequate management capacity should be important components of these reuse schemes. Some salinity management specialists promote the concept of reusing drainage water on successive crop types with increasing salt tolerance to maximize the volume transpired and minimize the volume of drainage water. An interesting example of this approach, known as the serial biological concentration concept, has been tested in an agriculture-forestry system since the early 1990s in California.

Box 6:
ACID SULFATE SOIL DRAINAGE

Acid Sulfate Soil Drainage in the Barito River Delta of Indonesia
Pulau Petak, an island in the delta of the Barito River in South Kalimantan, Indonesia, contains mainly acid sulfate soils. Before reclamation, the water table was high. Soils were protected from the air so that no oxidation and subsequent acidification took place. The area was covered by mangrove forest along the coast and by freshwater swamp forest inland. About 150,000 hectares have been systematically reclaimed since 1920. Of the originally reclaimed area, however, 75,000 hectares have been abandoned again because of acidification that resulted from the drainage.

Fish Deaths From Acid Sulfate Soil Drainage in Australia
Acid sulfate soils emerged as a significant environmental concern for Australia's sugar industry following a major incident in the Tweed River in New South Wales in 1987. Heavy rains occurred, following a long drought. Some days later, a 23-kilometer stretch of the river became clear and devoid of aquatic fauna for several months. The river was found to have become very acidic, with aluminum concentrations of 2.5 mg/l. The problem was traced to acid sulfate run-off from major drainage works from extensive sugarcane fields. It is believed that acidic waters accumulate in the soils and drains during dry periods, and are flushed into the river when heavy rains occur. Similar problems have reoccurred at regular intervals since.

Acid sulfate soils in the region have now been mapped and priority management areas have been identified. Different management actions are being tested in different parts of the area. In some parts, lime and organic mulch are being applied to neutralize the acidity; in other areas, the aim is to minimize the displacement of acidic groundwater to the river by laser leveling, planting in mounds, reducing the length of the drainage ditches to reduce the acid sourced from the drain banks, and liming drainage banks. After significant rain, pH still falls to around 3.5 for 3-4 days, before returning to about pH 8.0. Previously, acidic discharges would continue for some weeks. The discharge of acid has now been reduced by up to 80 percent.

Sources ILRI, 1994, Tulau, M.J. 1999. *Acid Sulfate Soil Management Priority Areas in the Lower Tweed Floodplains*. Sydney. Department of Land and Water Conservation.

INSTITUTIONAL CONSIDERATIONS

There has been widespread institutional reform in the irrigation sector in many countries in the last 15 years, primarily driven by a need for governments to reduce their expenditure on irrigation schemes. Both the methods for implementing these reforms and the results achieved have been mixed.

REGULATIONS AND ORGANIZATIONS

Institutions for I&D planning and management include both the rules (laws, regulations, customs) and the organizations that put those rules into practice through operations and maintenance activities (O&M). In many countries, both developing and developed, these institutional arrangements are not well designed for effective O&M. For example, water management is often dominated by government agencies that are remote from water users, inflexible and not business oriented. In developing countries, these agencies are also often underfunded for O&M, lack transparency and accountability, and are either overstaffed or lack motivated staff.

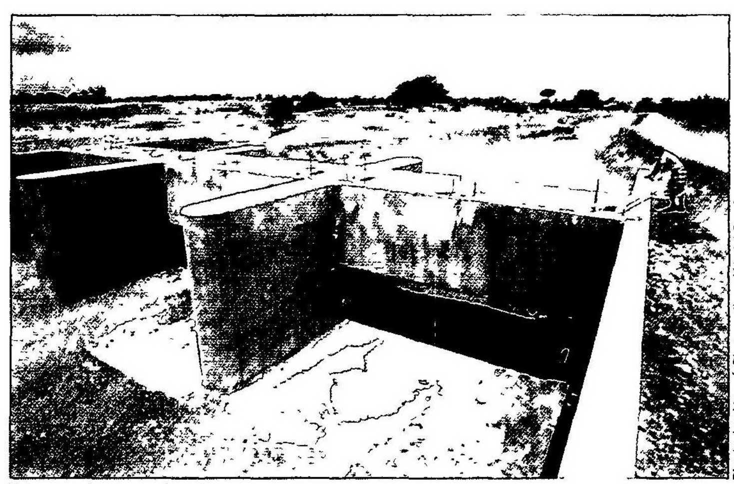

Weir under construction

Photo by Hervé Plusquellec, World Bank

There is no single model for effective planning and management of I&D schemes but some general principles are now widely recognized as being important (see Note B.2). First, there need to be clear responsibilities established in law for the planning and management of water resources. In particular, the regulation and operation of I&D schemes need to be separated, so that one agency is not responsible for both operating an I&D scheme and enforcing the laws governing the allocation of irrigation water and the discharge of drainage waters. Ideally, the planning and development of I&D should also be separated because in many countries design and construction of I&D schemes is a source of pride that drives the development of irrigation beyond what is necessary.

Second, to minimize the potential for conflict when water resources are scarce, the right to water use for irrigation needs to be clearly established. In many countries, there are locally understood but poorly recorded systems of water rights. Whether these rights need to be established in law or left to local custom is a decision that will depend on circumstances. The important principle is that the rights are widely understood and accepted.

Third, laws and rules governing I&D need to be enforced impartially. There are many instances where a well thought-out set of rules exist, but are not enforced because of lack of high-level support and the interference of influential land owners. Consequently, irrigators take surface and ground water beyond their allocations and discharge contaminated drainage water to receiving bodies of water.

Fourth, an increased emphasis needs to be put on drainage where it does not exist. Under-investment has contributed to a loss of productivity in very large areas.

Fifth, concerted policies and actions are needed to reduce the perverse subsidies for groundwater pumping. Phasing out such subsidies is both an economic and an environmental necessity.

Finally, the planning of I&D needs to be carried out as part of integrated water resources management. Otherwise, the basin's water resources might not be allocated to their socially best use. The importance of this IWRM approach is widely recognized by international agencies, and is incorporated into the World Bank's 1993 Water Resources Management Policy and its recent Water Resources Sector Strategy. The difficulty lies in implementing this concept. Sectoral interests are reluctant to give up their power; identifying the best allocation of water resources across a basin is technically difficult; and incorporating the concerns of end users can be difficult when they have not traditionally had a voice in decisionmaking. However, there is now enough experience to show that the benefits of an IWRM approach make it worthwhile overcoming these difficulties.

STAKEHOLDER PARTICIPATION

Stakeholder participation is a critical component of all stages in the development of I&D systems, including planning, design, implementation, operation, and maintenance. Water users in irrigation systems are particularly important stakeholders, since they normally receive direct benefits from the project and pay for system operation and maintenance upon its completion. But other stakeholders–such as those having concern for impacts on municipalities or villages, and those having interests related to the environment–also need to be involved. All stakeholders need to be involved from the beginning, since it is through their early involvement in the planning that they develop the ownership that is necessary for projects to be successful. Box 7 provides a good example of participatory planning in an area where water resources are heavily used.

Promoting management transfers and the participation of water users in the operation of irrigation systems has provided great opportunities for improving the performance of irrigation and drainage systems in many countries, including Turkey, India, and Mexico. There are many models for participation, ranging from privatization of irrigation and drainage districts to participatory involvement. Mexico has transferred ownership of entire irrigation districts to water users. Typically, a positively

BOX 7.
USANGU PLAIN IN TANZANIA

There were far fewer people in the Usangu Plain of Tanzania in the 1950s compared to today The initial people (Wasangu) were primarily livestock keepers. At that time, there were only small areas of rainfed cultivation and about 5,000 hectares of irrigated land. The natural vegetation was largely untouched, and the whole of the central grassland area of the plain was flooded every year. Since the 1950s, people from all over Tanzania have moved to the Usangu Plain, and over 26 different ethnic groups are now living there. Irrigation has been developed in parts of the southern plains, and cultivation of maize and sorghum has been developed in the western wetland areas. Meanwhile, a large national park has been declared in the north that is dependent on water from the river. Downstream from the park is Mtera Dam, a structure that regulates water for over 50 percent of the nation's hydropower production. Consequently, there is now intense competition for the limited water available.

Village and ward-level people were involved in participatory planning for the "Sustainable Management of the Usangu Wetland and its Catchment" water resource project. Development teams were set up and helped identify the resources available to them, issues of concern, and their ideas for the future. From these, village action plans were developed that made use of the local knowledge, skills, and resources to develop community-based and community-led solutions to village issues. Many of the issues in the village plans were concerned with competition over the use of limited natural resources. One solution was to make village land use plans, which required bringing together the different resource users to resolve conflicts over future use of the resources. Numerous tradeoffs were reviewed due to the multitude of resource uses, which included land uses for irrigation (45,000 ha), wetlands (1,800 km^2), grasslands (210,000 ha), catchment areas (20,811km^2), woodland/forest areas (1.085 million ha), and rainfed cultivated areas (430,580 ha). A great deal of effort went into managing conflicts related to water and other resources, as well as developing subcatchment resource management programs. This is part of an ongoing effort to manage the water resources of Usangu.

Source: The Sustainable Management of the Usangu Wetland and its Catchment, Project report 1998-2002 Ministry of Water and Livestock Development, Tanzania

reinforcing cycle occurs. Through involvement and a sense of ownership and control over the operations of the water distribution system, irrigators become more willing to pay water user fees. Consequently, the operational budget of the supply and distribution authority is expanded and a higher level of service is provided.

Clearly, to be effective, stakeholder participation needs to be accompanied by other reforms, including capacity building, reorganization of agencies, and technical improvements. Nevertheless, these improvements seldom succeed to the point where the irrigation district is able to operate independent of government or donor subsidies. The most successful examples occur where the political economy provides an enabling environment and the country has an advanced irrigation sector (Mexico, New Zealand, Turkey, the United States) or where there is a highly unequal distribution of land (South Africa, Colombia).[7]

The organization controlling a drainage system's operation and maintenance is usually formed at the local level. When other stakeholders, such as downstream communities dependent on the waterbodies receiving the drainage waters, are not involved in the important decisions about drainage infrastructure, there can be conflicts because of the off-site impacts of drainage. The management of water and the environmental conditions in the project area are a concern of many more people than the direct beneficiaries, and all need to be involved if such projects are to have long-term success and stability.

---

[7] Shah, T., B. van Koppen, D. Merrey, M. de Lange and M. Samad, 2002. *Institutional Alternatives in African Smallholder Irrigation: Lessons from International Experience with Irrigation Management Transfer.* Research Report 60. Colombo, Sri Lanka: IWMI.

QUANTIFYING IMPACTS OF I&D SCHEMES

ENVIRONMENTAL ASSESSMENT (EA) DURING PLANNING

An EA is required for lending operations that have potentially significant environmental impacts. Drainage portions of projects can cause particular concerns in relation to drinking water supplies and fish and wildlife habitat values, and thus should receive careful attention in EAs. Wetlands in particular are important to consider when drainage is involved, since drains located too close to wetland areas can severely degrade their functions and the services that they deliver to local communities. Natural wetlands in tropical, temperate, and humid climates are the normal areas of concern; in arid and semiarid areas, irrigation-induced wetlands are more common.

The more humid climatic areas often do not have salinity concerns; waterlogging of soils is the normal reason for draining them. Detailed information on wetlands can be found in Note G.3. In any arid or semiarid area, EAs should be used to develop insights into the drainage needed to mitigate the waterlogging and salinization impacts of irrigation projects. System design and management to reduce the mobilization and transfer of pathogens and toxic trace elements are also critical components in EAs for projects involving drainage.

In all such projects, the irrigation and drainage development should be considered as part of the development of a larger region or river basin. Box 8 provides an example.

For major I&D developments, the extent and severity of environmental impacts should be modeled prior to project development. A comprehensive list of parameters to model can be obtained from Mock and Bolton, 1993. This list was developed to identify environmental effects of irrigation, drainage, and flood control projects. Some parameters, such as hydrologic and salinity changes, can be predicted from existing models, but many items require projections that must be based on similar projects elsewhere where monitoring programs have been carried out properly. Models should not be prepared for project planning and then forgotten. They should be retained and improved as the project is implemented and the system is operated. Data from monitoring efforts need to be added to the model; they should be used to evaluate project operations and predict future impacts as well as to suggest improvements in management of the system.

MONITORING AND EVALUATION

Baseline studies should be undertaken before new I&D schemes are developed so the monitoring results can be interpreted. The monitoring, including the parameters to be measured, the data interpretation, and the dissemination methods, should be specified in Environmental Management Plans that are developed in response to the EA. However, it is often difficult to find funding to continue monitoring programs when the project is completed. Long-term monitoring is more successful with program-type approaches where longer-term commitments for funding are available. Some of the key items to monitor are noted in Box 9.

Monitoring should feed into decision making processes (see Note D.1). Analysis and interpretation needs to be carried out properly, and the results must be shared with stakeholders and management, alerting everyone to developing problems in time to correct them or plan for the consequences.

Box 8.
LIGUASAN MARSH IN THE PHILIPPINES

The Liguasan Marsh is one of the significant features in the Mindanao River Basin in the Philippines. The marsh region covers approximately 220,000 ha (of which 140,000 ha is cultivable during the dry season) in the central and lower reaches of the basin. The actual area of marshland is about 89,000 ha. A special area of 43,930 ha, the "Liguasan Marsh Game Refuge and Bird Sanctuary," was proclaimed as a protected area in 1940.

In the dry season, the inundated region consists of numerous interconnected areas that are well distributed throughout the central marsh. The soil is rich and the vast land and water resources provide tremendous potential for growth of wildlife habitat, fisheries production, and agricultural production. Within the marsh area, about 112,000 families use the area for fishing when the water levels are high, and agriculture when the water levels are low. During the dry season as much as 80 percent of the protected area is planted to crops such as corn and rice which are sustained by irrigation.

By absorbing the floodwaters from different tributaries, the marsh minimizes flash floods in the low-lying areas of the Mindanao River as it approaches the basin exit point in Illana Bay of Moro Gulf. Residents in the lower marshlands are dependent on the aquatic harvest as well as agriculture for their livelihood. Deforestation is one of the most pressing problems in the upstream watershed areas, leading to soil erosion and the continuous deposition of silt in different rivers of the basin. There is only limited environmental information available for the marsh. However, the area is known to support about 20 species of fish, 3 species of reptiles, and over 20 species of waterfowl, notably herons, egrets and ducks. It is also one of the last strongholds for the endangered Philippine Crocodile (*Crocodylus mindorensis*), and the Monkey-eating Eagle (*Pithecophaga jefferyi*) is reported to be present in the forested areas of the marsh. The marsh area is particularly rich in orchids.

The main threat to the marsh in the past has been drainage for rice cultivation and threats involving conversion of large areas to fish ponds. A development scheme has been proposed to create additional agriculture infrastructure and convert more of the lands surrounding and within the marsh area to irrigation. The scheme includes drainage, flood protection, irrigation, roads, and fisheries development. Some estimates indicate that with good flows in the rivers of the basin during the dry season, the extension of irrigation could be carried out to achieve 200 percent irrigated cropping intensity without the need for storage dams. Moreover, mangrove area rehabilitation and stabilization, improvement of wildlife habitat, and better access for development of tourism could possibly be part of the development framework. A comprehensive plan needs to be drawn up to balance the potential benefits of the scheme with the potential losses in wetland function (flood protection, biodiversity) and livelihoods for existing residents. However, planning for the development has not progressed because of the security problems in the region.

Source Internal World Bank Preparation Documents for The Philippines River Basin and Watershed Management Program

Box 9.
ITEMS TO BE CONSIDERED IN MONITORING PROGRAMS FOR IRRIGATION AND DRAINAGE

- Water volumes, surface water levels, and water quality changes for water flowing into the project area—at selected locations throughout the project area and at all discharge points over time.
- Shallow groundwater levels throughout the project area, particularly in low areas where waterlogging is most likely to occur.
- Aquifer piezometric levels and water quality to monitor changes and alert stakeholders to any degradation in water supply or potential drainage problems due to piezometric pressures.
- Soil qualities, to ensure that the measures carried out are not degrading the soil within or outside the project area. Characteristics such as acidification (acid-sulfate soils), surface sealing, compaction, subsidence (organic soils), consolidation (collapsible soils) and salinization (coastal, arid and semi-arid areas).
- Salinity changes in soil with time to check for sustainability of the area's agricultural system and problems related to developing salinization.
- Air quality in locations where wind erosion or pollution from industries or municipalities is a concern, since they affect agricultural production and health.
- Biological and ecological changes related to fish and wildlife habitats.
- Human health and incidence of disease, particularly waterborne diseases.

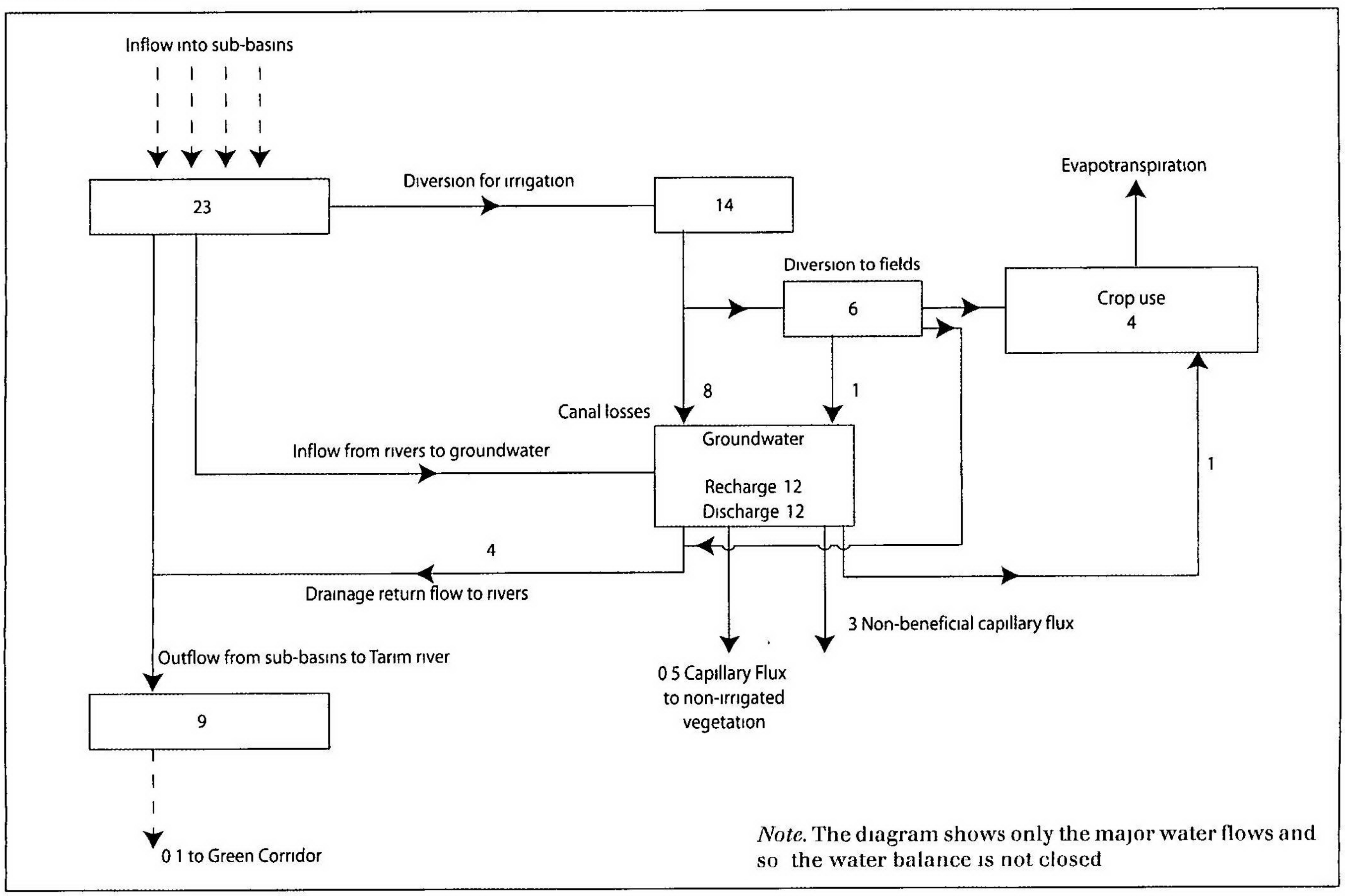
CASE STUDIES

CASE STUDY 1. THE LOP NOOR LAKE IN XINJIANG PROVINCE, CHINA

The Lop Noor Lake is situated in the eastern region of Xinjiang Province in China. The Lake was the center of the kingdom of Loulan, a strategic stopping point on the Southern route of the Silk Road during the Han and Tang periods. The lake's surface was highly variable because its water source, the Tarim River, depends on snow melt from mountain streams for water. The flow in the upper Tarim River was reduced following the intensive development of irrigation in several oases of the Tarim River basin. The lake progressively dried up during the 1960s and was completely dried up by the 1970s, leaving behind a vast expanse of salt deposits. The lower reaches of the Tarim River have also been affected. Herdsmen and farmers have been left without their livelihoods and the "green corridor", a 200-km-long area of natural riverine forests along both sides of the river, has been damaged.

Since then, better water management has been instituted. In six out of the seven sub-basins of the Tarim River, total irrigated area has increased by 45 percent, from 753,000 to 1,060,000 hectares since 1980, but the volume diverted for irrigation has increased by only 13 percent due to better management and lining of canals. Water balance studies for the five sub-basins in the on-going World Bank Tarim II project are depicted in Figure 3. The low efficiency is largely attributed to the high canal

FIGURE 3.
INDICATIVE GROUNDWATER AND SURFACE WATER BALANCE IN THE TARIM RIVER BASIN (BILLION M³/YEAR)



Note. The diagram shows only the major water flows and so the water balance is not closed losses, nearly 60 percent of the total diversion. Some part of these losses to groundwater is re-used by capillary flux to irrigated crops and nonirrigated vegetation, such as pasture and trees. Another part is lost by nonbeneficial capillary flux and some return flow to the rivers.

Canal lining is one of the most important components of the Tarim II project (see Note F.2). Canal lining will save water for downstream use, and will benefit irrigated agriculture through a reduction in nonbeneficial evaporation. Some local environmental losses due to the reduction of canal seepage will occur, since some canal-fed wetlands will dry out, and recharge to the Tarim River will be reduced.

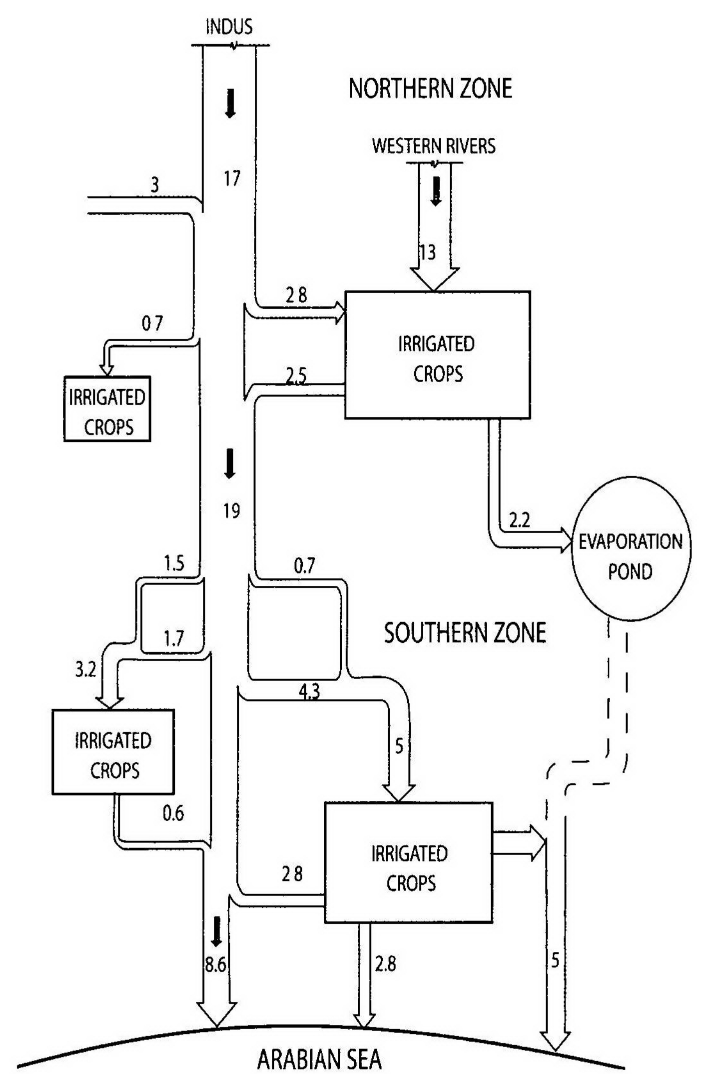
The objective of the project is not to restore the Lop Noor Lake but to preserve the green corridor to provide a vegetation barrier against progression of the desert. Half of the water saved in the project will be delivered downstream, with a minimum of 150 million m³ being assigned to the green corridor. The remaining water will be consumptively used by grazing land, forest areas, irrigation and through non-beneficial evapotranspiration.

CASE STUDY 2. WATERLOGGING AND SALINIZATION IN THE INDUS RIVER BASIN

The Indus River Basin lies in Pakistan and parts of India, stretching from the foothills of the Western Himalayas to the Arabian Sea. Before region-wide irrigation was initiated, the groundwater table lay scores of meters deep and the aquifer was in hydrologic equilibrium.

When large-scale irrigation was introduced early in the 20th century, an extensive water distribution network was established (including storage reservoirs, barrages, canals, and numerous unlined watercourses) to form the largest irrigation area in the world, covering about 15 million hectares. The efficiency of the distribution system, however, was very low, with less than half the water diverted from the rivers actually reaching the farmers' fields. Field irrigation efficiency was even lower–possibly about 30 percent. Since the natural groundwater drainage is inadequate and artificial drainage was not provided when the irrigation sys-

FIGURE 4.
EXAMPLE OF SALT BALANCE AND DISTRIBUTION – PAKISTAN PORTION OF INDUS RIVER BASIN (SALT IN Mt (MILLION TONS))



Note. Details are from the Drainage Sector Environmental Assessment for the Pakistan National Drainage Program.

tem was developed, percolation from the canals coupled with over-irrigation led to a rapid rise of the water table.

Waterlogging occurred first in areas along the canals and later spread to form contiguous areas. By 1960, the watertable was within 3 meters of the soil surface under about half of the canal command area, and within 1 meter of the surface over a tenth of the area, causing salt infusion to the root zone. Salt accumulations resulted in the salinization of about 1 million hectares. By 1980, the groundwater rose to within less than 3 meters on the surface underneath 55 percent of the total irrigated area. Salinization then affected an estimated 5 million hectares.

This alarming trend led the Pakistani government (with international assistance) to implement the Salinity Control Reclamation Projects (SCARP) program. Under SCARP, a regional drainage canal has been constructed and private users have been encouraged to install tubewells to pump water from places where the groundwater was of good quality. As a result, the water table ceased rising in large areas, and is even being lowered in some. In other areas, however, the rise continues.

The disposal of drainage water is particularly difficult and expensive, since many of the problem irrigated areas lie great distances from the sea, and the land surface is extremely flat (less than 1:5,000). The problem of drainage and effluent disposal is common to both the Pakistani and the Indian sides of the Punjab. Some evaporation basins have been used, but leakage back to the rivers during dry periods are problematic. The World Bank has been helping India and Pakistan develop plans for solving these long-term waterlogging and salinity problems.[8] An example of a salt balance related to the Pakistan portion of the Indus River Basin is given in Figure 4.

[8] Hillel, D. (2000).

FURTHER INFORMATION

Information about irrigation systems can be found in:

Hoffman, G. J., T. A. Howell, and K. H. Solomon, eds. 1990. *Management of Farm Irrigation Systems.* St. Joseph, MI: American Society of Agricultural Engineers.

Jensen, M. E., ed. 1980. *Design and Operation of Farm Irrigation Systems* ASAE Monograph Number 3. St. Joseph, MI: American Society of Agricultural Engineers.

Information about drainage systems can be found in:

International Land Reclamation Institute (ILRI). 1994. *Drainage Principles and Applications.* Publication 16, 2nd Edition. Wageningen, The Netherlands: ILRI.

Skaggs, R. W., and J. van Schilfgaarde, eds. 1999. *Agricultural Drainage.* Number 38 in the series "Agronomy." Madison, WI: American Society of Agronomy.

FAO. 1997. *Management of Agricultural Drainage Water Quality.* ICID & FAO Joint Report. FAO Water Report 13. Rome: FAO.

FAO. 2002. *Biodrainage – Principles, Experiences and Applications.* IPTRID Knowledge Synthesis Report No. 6. Rome: FAO.

Stirzaker, R. W., R. Vertessy and A. Sarre, 2001. *Trees, Water and Salt.* Canberra, Australia: Rural Industries Research and Development Corporation.

Information about environmental assessment can be found in:

Food and Agriculture Organization of the United Nations (FAO). 1995. *Environmental Impact Assessment of Irrigation and Drainage Projects.* FAO Irrigation and Drainage Paper 53. Rome: FAO.

Mock, J.F. and P. Bolton. 1993. *The Environmental Checklist to Identify Environmental Effects of Irrigation, Drainage and Flood Control Projects.* Wallingford, UK: HR Wallingford.

World Bank. 1991. *Environmental Assessment Sourcebook, Volume II – Sectoral Guidelines.* World Bank Technical Paper Number 140. Washington: World Bank.

Information about water quality can be found in:

FAO. 1985. *Water Quality for Agriculture.* FAO Irrigation and Drainage Paper 29 Rev. 1. Rome: FAO.

FAO. 1997. *Management of Agricultural Drainage Water Quality.* ICID & FAO Joint Report. FAO Water Report 13. Rome: FAO.

Information about salinity can be found in:

Christen, E.W., and J. E. Ayers. 2001. *Subsurface Drainage System Design and Management in Irrigated Agriculture: Best Management Practices for Reducing Drainage Volume and Salt Load.* CSIRO Land and Water, Australia Technical Report 38/01. (Available on the web at www.clw.csiro.au/publications/technical/2001).

Hillel, D. 2000. *Salinity Management for Sustainable Irrigation: Integrating Science, Environment, and Economics.* Washington: World Bank.

Umali, D. 1993. *Irrigation-Induced Salinity.* World Bank Technical Paper No. 215. Washington: World Bank.

Information about health effects from I&D schemes can be found in:

Birley, M. H. 1989. *Guidelines for Forecasting the Vector-borne Disease Implications of Water Resource Development.* WHO, FAO, and UNEP - PEEM Guideline Series 2. Geneva: WHO.

FAO. 1997. *Management of Agricultural Drainage Water Quality.* ICID & FAO Joint Report. FAO Water Report 13. Rome: FAO.

The following are useful website links:

www.clw.csiro.au
www.fao.org
www.icid.org
www.iwmi.org
www.rirdc.gov.au
www.worldbank.org

Other references in this Note:

Schultz, B. 2001. "Irrigation, Drainage and Flood Protection in a Rapidly Changing World." *Irrigation and Drainage* 50: 261-77.

Skaggs, R., et al. 1994. "Hydrologic and water quality impacts of agricultural drainage." *Critical reviews in environmental science and technology*, 24(1): 1-32.

Smedema L K. 2002. *Land Drainage: An Instrument for Agricultural and Rural Development.* International Commission for Irrigation and Drainage. Proceedings on CD.

Subramanian, A., N. Vijay Jagannathan, R. Meinzen-Dick, eds. 1997. *User organizations for sustainable water services.* World Bank Technical Paper No. 354. Washington: World Bank.

Szabolcs, I. 1989. *Salt-Affected Soils.* Boca Raton, FL: CRC Press.

Szabolcs I. 1994. "Soils and salinization." In M. Pessarakli, ed., *Handbook of plant and crop stress.* New York: Marcel Dekker.

World Bank. 1993. *Water Resources Management.* World Bank Policy Paper. Washington: World Bank.

The World Bank

Environment Department
The World Bank
1818 H Street, N.W.
Washington, D.C. 20433, U.S.A.
www.worldbank.org
For information on these publications contact the
ESSD Advisory Service at eadvisor@worldbank.org
or call 202.522.3773

PRINTED WITH SOY INK