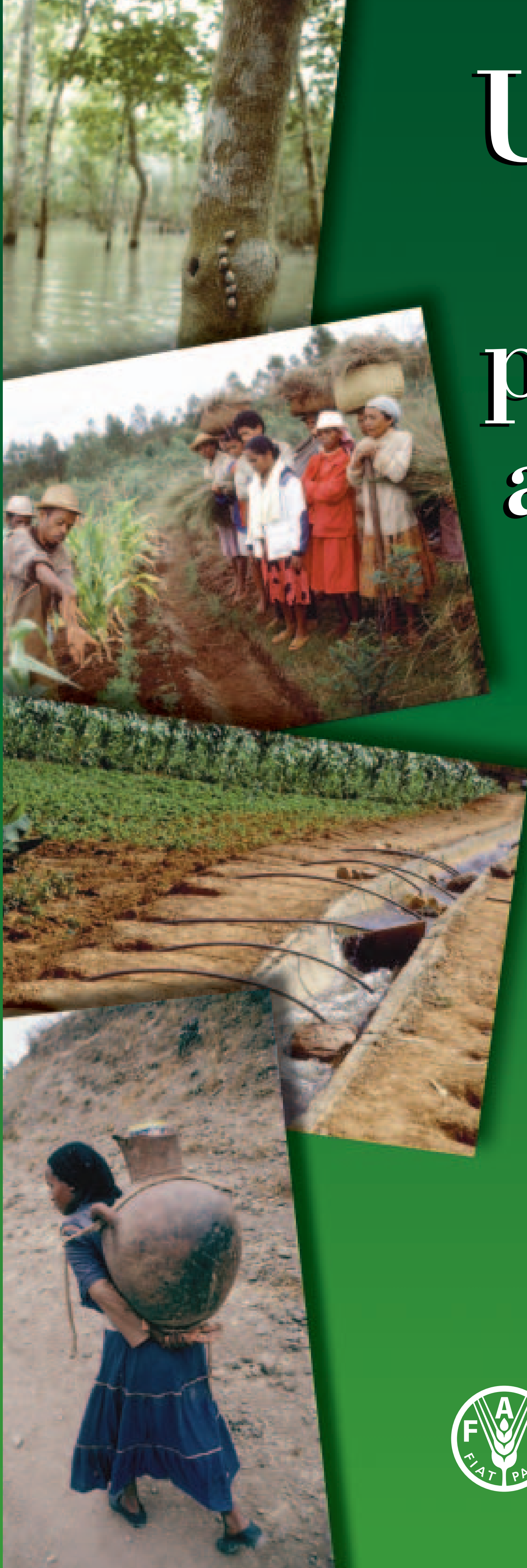
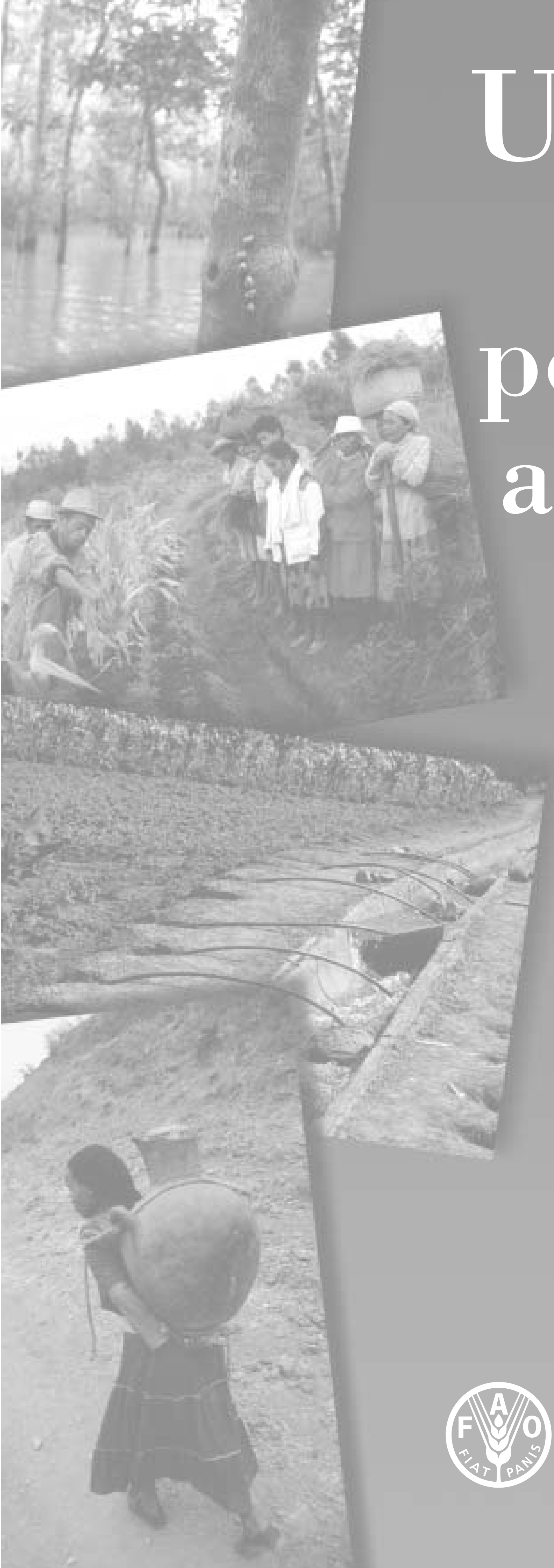


Unlocking the water potential of agriculture

Unlocking the water potential of agriculture



Foreword

On the occasion of the third World Water Forum (WWF-3), being held in Kyoto, Japan, from 16 to 23 March 2003, the Food and Agriculture Organization of the United Nations (FAO) presented an overview of the priority issues facing the agricultural decision-makers of the world in the field of agricultural water development and their implications for the management of water resources in a wider context. FAO has placed its participation in the WWF-3 debates in Kyoto under the motto "unlocking the water potential of agriculture". Indeed, all the statistical evidence confirms agriculture as the key sector for water management both now and in the coming decades. Nevertheless, the rural water development sector is currently failing to achieve priority compared with other competing sectors in international fora. At present, rural water promoters lack a valid strategy and marketing presentation to keep the focus on the issues. Strong, new arguments are needed in order to bring rural water back 'on line':

(1) The productive use of water for agricultural production and rural development will need to improve continuously in order to meet targets for food production, economic growth and the environment. This will require the progressive modernization of agricultural water management in a way that makes it both much more demand responsive and also better adapted to local climate, environmental and socio-economic conditions.

(2) Agricultural water management will be key to maintaining food security and income generation for the rural poor. However, the equitable management of local water resources can only be achieved through much greater involvement of rural communities and individual farmers.

(3) Sustaining these productivity and equity objectives can only be achieved through higher quality investment in the agriculture sector. Therefore, investment in agricultural water management will need to become much more strategic in improving: (i) the management of existing water infrastructure; (ii) the engagement of water users; and (iii) the use of innovative agricultural practices.

In the future, agriculture will have to respond to changing patterns of food demand and contribute to the alleviation of food insecurity and poverty among marginalized communities. In so doing, agriculture will have to compete for scarce water with other users, while reducing pressure on the environment. Water will be the key agent in the drive to raise and sustain agricultural production in order to meet these multiple demands. Therefore, agriculture policies and investments will need to become much more strategic. They will have to unlock the potential of agricultural water management practices to raise productivity, spread equitable access to water and conserve the natural productivity of the water resource base.

Acknowledgements

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List of Acronyms

EIA	Environmental impact assessment
GIS	Geographical information system
IFPRI	International Food Policy Research Institute
IIASA	International Institute of Applied Systems Analysis
IRRI	International Rice Research Institute
IWMI	International Water Management Institute
IWRM	Integrated water resource management
NGO	Non-governmental organization
O&M	Operation and maintenance
OECD	Organisation for Economic Co-operation and Development
SRI	System rice intensification
USDA	United States Department of Agriculture
WHO	World Health Organization
WUA	Water user association

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chapter 1

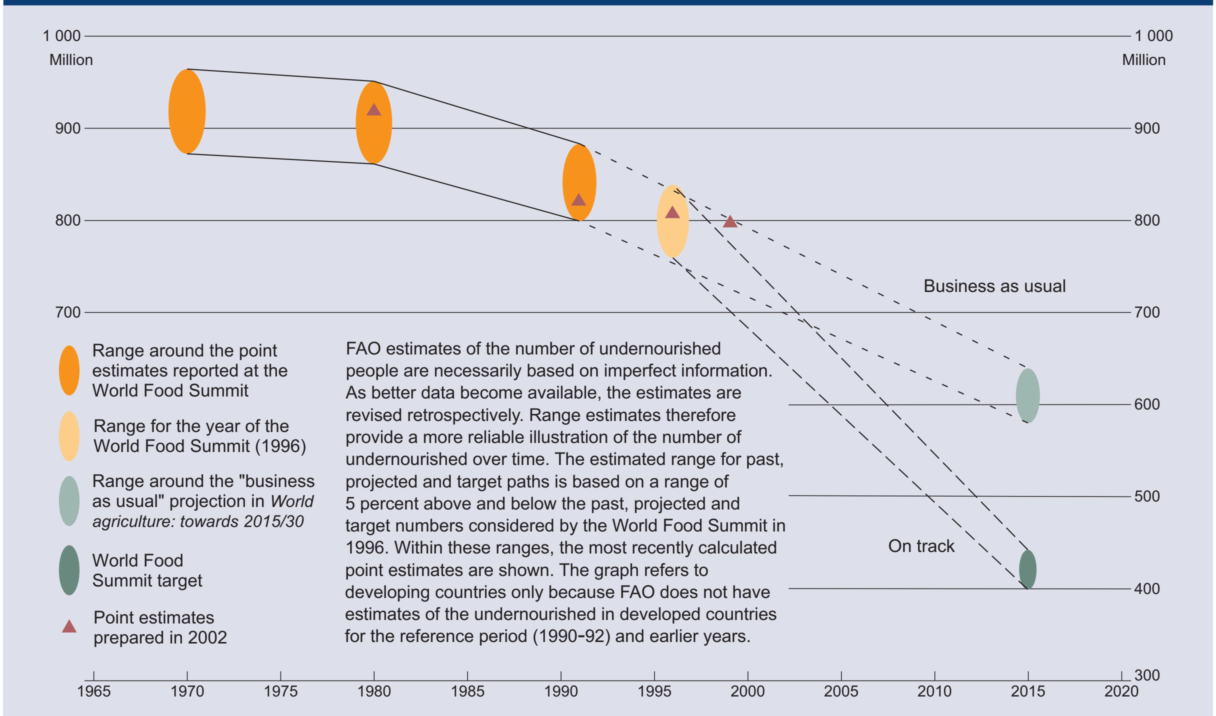
Introduction

Although enough food is being produced to feed the world's population, there are still some 840 million undernourished people in the world, 799 million of whom live in developing countries (FAO, 2002a). This situation led the World Food Summit in 1996 to set a goal of halving the number of hungry people by 2015. The recent FAO State of Food Insecurity in the World Report concludes that progress towards this goal has slowed to almost zero (**Figure 1**). The data indicate that the number of hungry people has decreased by 2.5 million/year since 1992. If this trend continues at the current pace, the World Summit's goal will be achieved more than 100 years late. To reach the goal by 2015, the annual decrease in the number of hungry people would have rise tenfold to 24 million. As Jacques Diouf, FAO Director General, says in the foreword to the 2002 State of Food Insecurity in the World Report, the cost of inaction is prohibitive; the cost of progress is both calculable and affordable.

Closer examination of the data reveals that the small global gains are the result of rapid progress in a few large countries. China has reduced the number of undernourished people by 74 million people since the benchmark period of 1990-92. Indonesia, Viet Nam, Thailand, Nigeria, Ghana and Peru have all achieved reductions of more than 3 million, helping

Figure 1 The undernourished in the developing world: comparisons with the World Food Summit target

Source: FAO, 2002a



to offset an increase of 96 million in 47 countries where progress has stalled. If China and the other six countries are set aside, the number of hungry people in the rest of the developing world has increased by more than 80 million since the benchmark period. Although in many countries the proportion of hungry people has decreased, the actual numbers have increased because of population growth. For example, the number of undernourished people has increased by 18 million in India although the proportion has fallen from 25 to 24 percent.

Sub-Saharan Africa continues to have the highest prevalence of undernourishment and it also has the largest increase in the number of hungry people. However, there are large differences between African countries. The Central Africa subregion is in the most critical situation: the number of hungry people in the Democratic Republic of the Congo has tripled following the country's collapse into warfare. On the other hand, the percentages and the numbers of undernourished people have declined most in West Africa. There have also been improvements in the situations in Southeast Asia and South America. The situation in Central America, the Near East and East Asia (excluding China) gives reason for concern as both the percentages and the numbers of undernourished people are increasing (FAO, 2002a).

For some time, experts have debated the capacity of the world's agricultural systems to produce enough food for an ever-larger population. FAO has maintained consistently that, on the basis of availability of suitable land for rainfed and irrigated agriculture, enough food could be produced for the much larger human population predicted for 30 years from now. It appears that in an increasing number of regions, land and water could be the main factors limiting food production. The objective of this paper is to examine present and future water availability for food production at a time of increasing demands for water from other users, e.g. for sanitation and drinking-water in mega-cities and for industry. Farmers not only have to compete for water with urban residents and industries, but increasingly also with the environment as its services in sustaining good-quality water supplies through wetlands and groundwater aquifers become more widely recognized. The latter demand has not yet been quantified accurately.

Any attempt to determine whether there will be enough water to grow food for the almost 8 000 million people expected to inhabit the Earth by 2025 requires an understanding of the link between water availability and food production. Once this relationship is understood, decision-makers can perceive more clearly the consequences of the choices they make in order to balance water supply and demand. There have been more than 20 estimates of future world food security in the past 50 years, based on various, increasingly complex, computer models. FAO and the United States Department of Agriculture (USDA) have produced regular forecasts, but others, such as the Organisation for Economic Co-

Plate 1 Irrigation of a potato field (Cape Verde)


FAO/17124/M. MARZOT

operation and Development (OECD), the International Food Policy Research Institute (IFPRI), and the International Institute of Applied Systems Analysis (IIASA) have also published their own forecasts. Others, such as the International Water Management Institute (IWMI), have made projections of future water-use scenarios. Whatever model one may adopt, it is clear that agricultural water use will still increase, albeit at a diminushing rate, if the growing world population needs are to be met.

During the last half of the 20th century, significant productivity gains in rainfed and irrigated agriculture have kept world hunger at bay. Improved water management and conservation in rainfed and irrigated agriculture have been instrumental in achieving these gains. Agricultural water management has underpinned the intensification attributable to fertilizer application and the use of high yield varieties. In this sense, water productivity alone is estimated to have increased 100 percent over the past 40 years.

In the future, agriculture will have to respond to changing patterns of demand for food and combat food insecurity and poverty amongst marginalized communities. In so doing, it will have to compete for scarce water with other users and reduce pressure on the water environment. Water will be the key agent in this drive to raise and sustain agricultural production to meet these multiple demands. Agriculture policies and investments will therefore need to become much more strategic. They will have to unlock the potential of agricultural water management practices to raise productivity, spread equitable access to water, and conserve the natural productivity of the water resource base. Some of the key issues related to these new challenges are discussed in details in this report.

Chapter 2 discusses the present and future availability of water resources. It draws on the outcomes of several of the computer models that predict future water use in agriculture. Rainwater, canal water and pumped groundwater are all essential for food production. Chapter 2 discusses their differing roles in poverty alleviation and rural development. They also differ from one another in the challenges they present when they are used in efforts to increase water productivity in agriculture, defined as crop yield per unit of water consumed.

Chapter 3 addresses the issues arising from the desire to enhance water productivity in agriculture. It explains that water productivity values depend on the scale at which they are assessed. It is widely assumed that reductions in seepage and percolation losses from fields can increase water productivity in many irrigation systems. However, where these so-called losses are pumped up from the groundwater and used for irrigation somewhere else, what is lost at one location is a water source elsewhere. This is illustrated by the difference between the perceived field irrigation efficiency (i.e. the fraction of water extracted for irrigation that reaches the fields) in Egypt's irrigation systems of about 40 percent and the calculated irrigation efficiency for the entire Nile Basin of almost 90 percent. The difference results from the widespread reuse of drainage water (Keller and Keller, 1995).

Chapter 4 examines risk management in agriculture. It discusses why farmers prefer low-input farming practices that result in low but stable production. It examines the incentives, especially with respect to water management, that can be provided to make them accept more risk but also produce more. It finds that part of the answer for irrigated agriculture lies in the provision of better management services leading to greater reliability of the water supply. In rainfed agriculture, part of the solution may come from the introduction of techniques that result in a more favourable partition between the amount of rain stored in the rootzone and that which runs off into drains.

Chapter 5 discusses approaches to reduce the adverse environmental impacts of water resource development. There used to be more than 1.6 million ha of wetlands in California, the United States of America, but more than 90 percent of these have now been drained and converted to others uses (Van Schilfgaarde, 1990). Similar statistics could probably be found for other countries and regions that are irrigated intensively. The development of water resources has considerably reduced the abundance of streams, riparian vegetation and wetlands suited for wildlife habitat. It is only recently that the world has realized that wetlands provide valuable 'ecosystem services', such as recharging groundwater, attenuating floods, and buffering sediment and pollution.

Chapter 6 focuses on the modernization of irrigation water management. In the past

30-40 years, many irrigation systems in developing countries have been rehabilitated. This rehabilitation was usually necessitated by years of neglect (often caused by lack of funds) and intended to restore the irrigation system to its original design. The impact of such rehabilitation work was often short lived. Where the management is incapable of operating and maintaining a system to high standards, restoring its physical infrastructure will not lead to production improvements. The converse is also true: good management cannot obtain good results from a poorly designed or maintained system. Moreover, what may have been appropriate in the past may not be suitable for today's water service demands and expectations. Thus, modernization encompasses improving the physical infrastructure and institutional setup so that the modernized system can function in a more service-oriented manner that is suitable for current and future cropping patterns and irrigation practices.

FAO (1997) defines irrigation modernization as a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation systems combined with institutional reforms, with the objective to improve resource utilization (labour, water, economic, environmental) and water delivery service to farmers.

The final chapter of this paper highlights the choices that governments and funding agents face in trying to ensure that water scarcity will not curtail the world's capability to produce enough food for the future global population.

chapter 2

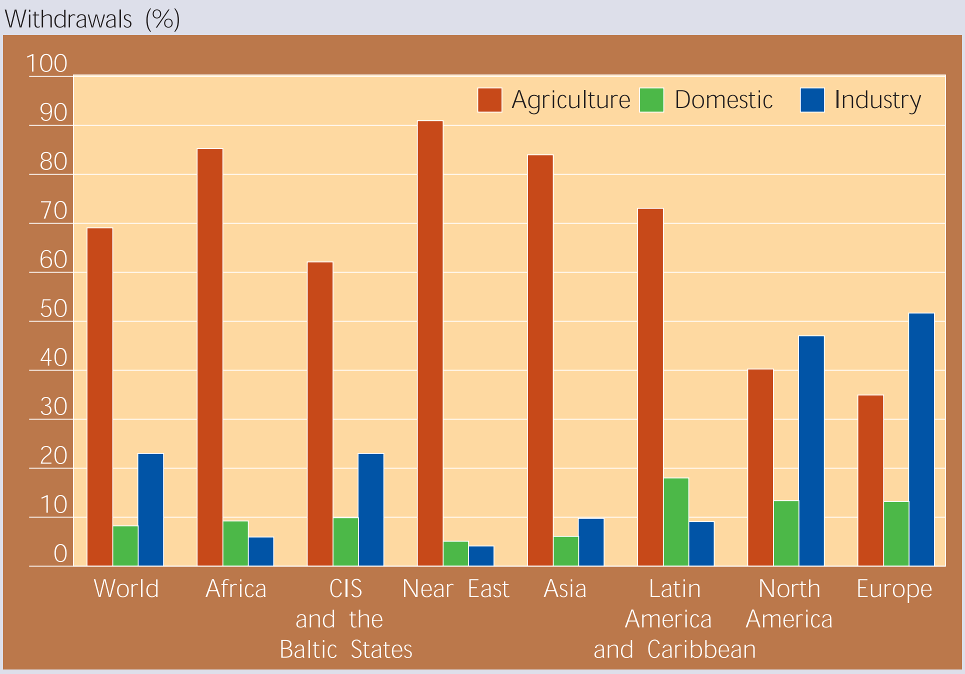
Water for sustainable food production, poverty alleviation and rural development

Almost all of the water of the planet occurs as saltwater in the oceans. Of the 3 percent of the global resource that is freshwater, two-thirds comes as snow and ice in polar and mountainous regions. Hence, liquid freshwater constitutes about 1 percent of the global water resource. At any one time, almost all of this occurs as groundwater, while less than 2 percent of it is to be found in rivers and lakes. In the temperate, humid climates, about 40 percent of the precipitation ends up in the groundwater, and for Mediterranean-type climates the figure is 10-20 percent. For the truly dry climates, the value can be virtually zero (Bouwer, 2002). Not all the water in rivers and lakes and in the groundwater is accessible for use because part of the water flows in remote rivers and during seasonal floods that cannot be captured before the water reaches the ocean. An estimated 9 000 – 14 000 km^3 of water is economically available each year for human use. At most, this represents 0.001 percent of the estimated global water. At present, annual withdrawals of water for human use are about 3 600 km^3. This may give the impression that there is plenty of water available that could be withdrawn for human use. However, part of the available surface water must remain in the rivers and streams to ensure effluent dilution and safeguard the integrity of the aquatic ecosystem. How large this part should be is little understood. It varies with the time of year, and each river basin has its own specific ecological limit below which the system can be expected to degrade. A global estimate for this demand is 2 350 km^3/year. Adding this to the amount withdrawn each year for human use results in nearly 6 000 km^3 of economically accessible water that is already committed (FAO, 2002b). This indicates that globally the margin is fairly small. Because water and population are distributed unevenly throughout the world, the water situation is already critical in various countries and regions and likely to become so in several more.

Agriculture is the principal user of all water resources taken together, i.e. rainfall (so-called green water) and water in rivers, lakes and aquifers (so-called blue water). It accounts for about 70 percent of all withdrawals worldwide, with domestic use amounting to about 10 percent and industry using some 21 percent (**Figure 2**).

There is an important distinction between water withdrawn for use and water actually consumed. In irrigated agriculture, about half of the water withdrawn (with considerable variation in this figure) is consumed in evaporation and transpiration from plants and moist soil surfaces. Some of the plants that contribute

Figure 2 Water withdrawals by region and by sector *Source: Crops and drops. FAO, 2002*



to this evapotranspiration process are unproductive weeds and plants on wasteland. Water that is abstracted but not consumed infiltrates the soil and is stored as groundwater or flows back through drains into rivers. This drainage water is generally of a lower quality than the water originally withdrawn owing to contamination by agrochemicals and salts leached from the soil profile. Compared with a return flow of 50 percent of the water withdrawn for agriculture, 90 percent of the water for domestic use is returned to rivers and aquifers as wastewater, while industry typically returns up to 95 percent. Poor-quality return flows from urban and industrial areas are sometimes treated before being returned to watercourses, but the non-point character of agricultural pollution makes treatment difficult. In this sense, agricultural water pollution may be better handled by controlling quantitative use and outflow from agricultural land.

THE SIGNIFICANCE OF RAINFED PRODUCTION

Rain is the source of water for crop production in the more humid regions of the world where some 60 percent of the world's food crops are grown. Rainfed agriculture takes place on some 80 percent of the arable land and irrigated agriculture produces 40 percent of the world's food crops on the remaining 20 percent. In order to meet future food demands, it is expected that relatively more crops will have to be grown on irrigated than on rainfed land, such that about equal amounts will come from both types of areas. Given the importance of rainfed cereal production, insufficient attention has been paid to potential production growth in rainfed areas. Most attention usually focuses on the possible expansion of irrigated areas. However, increasing cereal yields in rainfed temperate countries, better plant protection and manure techniques, and the use of supplemental irrigation in more arid countries indicate the significant potential for improving rainfed agriculture.

In arid regions, water scarcity is the result of insufficient rainfall. Semi-arid regions may receive enough annual rainfall to support crops but the rainfall is distributed so unevenly in space and time that rainfed agriculture is barely possible. Rainfall variability generally increases with a decrease in annual amounts and it is particularly high in the Sahelian countries. These regions are known for their periodic droughts that may last several years. Rain in semi-arid regions also tends to fall in a few hard showers. Such rainfall is difficult to capture for agricultural use. This leads to large amounts of runoff going into drains and eventually seeping down to the groundwater or to rivers. Where river discharge is large and difficult to manage, one way to capture the flow is through spate irrigation in which part or all of the river flow is diverted into fields surrounded by high bunds. In this way, one irrigation of up to 50 cm can provide enough soil moisture for a wheat crop even in the skeletal soils found in Yemen. Floodwater harvesting takes place within a streambed and entails blocking the water flow. This causes water to concentrate in the streambed. After the flood season is over, the streambed area where the water collects is cultivated. A terraced wadi (ephemeral stream) system is one type of floodwater harvesting. Here, a series of low check dams are constructed across a wadi and the wadi area is cultivated. Too much flow will breach the check dams or the diversion structures in spate irrigation. The suitability of these methods also depends on the soil conditions and depth of the wadi bed. Water harvesting, which is the collection

Plate 2 Canal intake and bank-protection gabions built under irrigation repair programme (Afghanistan)

FAO/18048/M. GRIFFIN

and storage of surface runoff, has also proved useful in semi-arid regions with infrequent rains (Chapter 3).

Although there is a great variety of such rainwater technologies, it is not clear whether their widespread use is always feasible, especially for poor farmers. The costs involved in the construction and maintenance of the water harvesting system play a major role in farmers' decisions on whether to adopt the technique or not. In the past, water harvesting systems were often installed with financial support from outside agencies, such as NGOs and international funding agencies. Many of those systems failed because of lack of involvement of the beneficiaries and their inability to organize and pay for maintenance. Rosegrant *et al.* (2001) report construction costs for water harvesting systems in Turkana, Kenya, of US$625-1 015/ha. Labour and construction constitute the bulk of the water harvesting costs as the opportunity cost for using the land is essentially zero. The initial high labour costs of building the water harvesting system often provide a disincentive for adoption of the technique. Moreover, many farmers in arid or semi-arid areas do not have the human resources available to move the large amounts of earth necessary in the larger systems. Therefore, small-scale water and soil conservation techniques that are applicable at field level are often adopted more easily. Investments on a larger scale require the existence or creation of community organizations both to pay for the necessary investment and maintenance, and to manage the benefits of the water harvesting infrastructure. Maintenance of the system is sometimes required in the rainy season when labour is relatively scarce and therefore expensive because of competition with conventional agriculture (Tabor, 1995). Notwithstanding these reservations about the widespread applicability of extensive water harvesting systems, model studies indicate that there is significant scope for increasing rainfed production provided that appropriate investments and policy changes are made (Rosegrant *et al.*, 2002). Crop breeding specifically for rainfed environments is crucial to future cereal growth. Chapter 3 discusses integrating crop and water resource management.

THE GROWING ROLE OF GROUNDWATER

Groundwater use for irrigation presents a paradox: regions where the groundwater resource has been overdeveloped coexist with regions with considerable potential for development of groundwater for use in irrigated agriculture (**Box 1**). A corollary is the so-called fallacy of aggregation: in aggregate terms, at the global or even national level, groundwater availability appears far in excess of present use. The annual groundwater use for the world as a whole has been placed at 750 – 800 km^3 (Shah *et al.*, 2000). This figure may appear modest compared to the overall groundwater reserves, but only a fraction of the world's groundwater reserves are economically available for agriculture. It is estimated that

Box 1 Overabstraction and sustainability: complex theory, simple practice

Source: Burke and Moench, 2000

There remains confusion in the usage of the terms 'overabstraction' and 'groundwater mining'. The latter refers solely to the depletion of a stock of non-renewable groundwater, so leaving the aquifer dewatered indefinitely. The planned mining of an aquifer is a strategic water resource management option where the full physical, social and economic implications are understood and accounted for over time. However, the replenishment of aquifers by downward percolation of rainwater shows high interannual variability and is a complex physical process that is difficult to evaluate. A declining water table does not necessarily indicate overabstraction of the groundwater resource. Overabstraction should not be defined in terms of an annual balance of recharge and abstraction. Rather, it needs to be evaluated over many years, as the limit between non-renewable stock and the stock that is replenished by contemporary recharge from surface percolation is usually unknown.

What is important to decision-makers and well users is the overall reliability and productivity of a well (in terms of water levels, volumes and water quality) during a given time period. Therefore, if a well taps a particular aquifer, what is its sustainable rate of exploitation, given variable periods of recharge and drought? The answer to this question is not trivial, and requires a certain level of precision in understanding the system dynamics. Where the system dynamics are understood, the maximum available drawdown can be calculated from a non-linear equation. This equation can be resolved by an analytical approach or through the application of numerical models. Where the aquifer system is sufficiently well known, the assigned value of the maximum available drawdown may also include the exploitation of a portion of the non-renewable groundwater resource. Such methods can provide a basis for pre-empting aquifer degradation before physical and socio-economic damage is done, by giving indications to users of sustainable abstraction rates.

about 30 percent of the world's irrigation supply is made up by groundwater but this input accounts for some of the highest yields and highest value crops (FAO, 2003).

The number of tubewells providing water to irrigated land in India, China, Pakistan, Mexico and many other countries has grown rapidly in the past 40 years. For example, some 60 percent of irrigated cereal production in India depends on irrigation from groundwater wells. This has led to widespread and uncontrolled overabstraction of the resource and the creation of a 'bubble' groundwater economy (Roy and Shah, 2002). In Yemen, abstraction is estimated to exceed recharge by 400 percent (**Box 2**). Groundwater abstraction and recharge have rarely been quantified accurately. This should be a first step in assessing the potential for further development of the resource and designing management approaches (**Box 2**). Where irrigated agriculture depends in part on pumped groundwater, many of the command areas present a mosaic of irrigation methods. These range from totally irrigated by canal water to entirely fed by pumped groundwater, with most of the fields having some combination of the two. Hence, irrigation is by definition conjunctive, but there are few examples of conjunctive management.

In China, 52 percent of the irrigated lands are (at least in part) served by tubewells. As a result of overabstraction of groundwater, water tables have fallen by up to 50 m over the last 30 years. For example, in the Fuyung Basin in north China, surface water has been curtailed drastically in order to meet industrial demand, and farmers have responded by resorting to groundwater irrigation. The root of the Asian groundwater crisis alluded to by Shah *et al.* (2000) that threatens millions of poor rural communities lies in the open access nature of the resource. Paradoxically, it is precisely this feature of

Box 2 Participatory modernization of water management to reduce overabstraction of groundwater in Yemen

Source: Dixon et al.*, 2001*

The immediate consequence of the continuous decline in water resources in Yemen has been household food insecurity, especially for poor families in vulnerable rural areas. The only viable option is to improve the management of the available resources through the introduction of appropriate technologies and management tools.

In 1995, conscious of these issues, the Government of Yemen launched a programme to improve the general efficiency of irrigation with groundwater. It included the Land and Water Conservation Project (financed by the World Bank). This project is based on cost sharing, farmer participation and modern irrigation technologies.

Water savings achieved at the farm level have ranged from 10 to 50 percent. At the regional level, the savings in water use have averaged at least 20 percent and have reached as high as 35 percent, particularly in northwest Yemen where most of the farms are equipped with bubbler irrigation systems. Considering the current operational costs that farmers pay for pumping water (even with relatively low energy costs), the cost of investing in modern equipment is recovered in 2-4 years through water savings alone. In addition, the new technology offers benefits beyond water savings. These include significant improvements in yield and product quality, resulting from changes in cropping patterns and increases in the irrigated area.

groundwater in shallow aquifers that has made it a powerful tool in the fight against poverty (Moench, 2002), i.e. that everyone who can afford to install a pump has free access to water. Irrigation with groundwater is generally more productive than canal irrigation because groundwater is produced close to where it is used with hardly any losses during transport. In addition, farmers are in control of the timing and amount of the water extracted. Evidence in India suggests that crop yield per cubic metre of water on groundwater-irrigated farms tends to be 1.2 – 3 times higher than on farms irrigated with surface water (Shah *et al.*, 2000).

Throughout the world, most groundwater development has proceeded primarily on the basis of individual initiatives. Unlike surface irrigation or drinking-water supply projects where government agencies are generally involved in many aspects of design, financing and implementation, most groundwater development is driven by the decision of individual farmers to drill wells and buy pumps. While governments often facilitate this process through subsidies and rural electrification, large implementation departments are rare. In consequence, there are very few government agencies that have frequent and direct contact with groundwater users. Furthermore, surface water development generally involves the diversion of flows or the construction of storage on a clearly defined stream or water body. The impact of such actions on downstream users is generally clear, at least in a conceptual sense. As a result, large bodies of customary and formal law along with the resource monitoring and enforcement systems required to implement them have developed over the long history of surface water development. This is not generally the case with large-scale groundwater development. It is a recent phenomenon and diversions have a far less directly observable impact on other users. As a result, groundwater extraction remains highly ‘individualistic’ and tends to occur outside the framework of established institutions for allocating, monitoring or managing the resource base. In locations such as India, tens of millions of individuals own and operate wells. Most of these wells are on private lands. The location, use and even existence of such wells is often unknown to any individual aside from the owners and their immediate community. As a result, no established institutional basis for management exists.

THE ROLE OF SURFACE WATER COMMANDS

Global indicators of water scarcity tend to ignore variations in the importance of irrigated agriculture for food security among countries. They also fail to account for seasonal differences in supply. For example, more than 70 percent of the total supply in India occurs in the three monsoon months of June, July and August, when most of it floods out to the sea. Moreover, countrywide data ignore regional differences in water supply and withdrawal within the country, an example of the aggregation fallacy. Regardless of these caveats, most observers conclude that many countries do not have a surplus of water available for irrigation. In fact, many countries do not have sufficient annual water withdrawal to irrigate their potential gross irrigated area even at high basin-irrigation efficiencies. Basin-irrigation efficiency includes all reuse of drainage water and is considerably higher than system-irrigation efficiency where drainage flow from one system is used for irrigation again downstream in another system. Most analyses indicate that, whatever the water scarcity indicator used, more than half of the world's population lives in countries with varying degrees of water scarcity. This scarcity can be physical (there is no more water), economic (the country cannot afford to develop additional water resources) or caused by a lack of social adaptive capacity. Examples of adaptive capacity are the ability

Plate 3 Farmlands under water as a result of flash floods (Bangladesh)

FAO/9367/T. PAGE

to produce more value per unit water consumed, and imports 'virtual water', which is the water used to produce the crops obtained on the world market (Allan, 1995) (Chapter 3, Box 5).

There is concern that more people may be affected by food insecurity as a result of water scarcity. Competition for the same resources combined with the increasing trend of water pollution exacerbates this problem. Moreover, the largely unknown impact of climate change may make water scarcity in some countries more severe. Several studies suggest that rice yields are likely to increase in the higher latitudes and decrease in the lower latitudes under future climates. It is likely that the poorest countries (and the poorest people within them) will suffer disproportionately as they are less able to adapt to the changing conditions. Future projections by the IFPRI (based on their model studies) indicate that water withdrawals will rise by some 22 percent between 1995 and 2025. Projected withdrawals in developing countries will increase by 27 percent in the 30-year period, compared with 11 percent in developed countries (Rosegrant *et al.*, 2002). Only a very small increase in irrigated area is expected, which will be more than offset by increases in river basin efficiency.

However, FAO expects that the overall water withdrawal for irrigation in all developing countries will increase from 2 128 km^3 in the benchmark period of 1997/99 to 2 420 km^3 in 2030, an increase of nearly 14 percent. FAO further expects the irrigated area in developing countries as a whole to increase from 202 million ha in 1997/99 to 242 million ha by 2030, an increase of nearly 20 percent. The largest increase is expected in sub-Saharan Africa with 44 percent, and the lowest in East Asia with 6 percent. The expected increase is 32 percent for Latin America, about 10 percent for the Near East/North Africa and 14 percent for South Asia (FAO, 2002c; Faurès *et al.*, 2002). The effectively cultivated irrigated area is expected to grow by 34 percent during the period under consideration, because of higher cropping intensities. Much of the difference in the rates of increase of water withdrawal and irrigated area relates to the higher water productivity in irrigated agriculture that is expected to have occurred by 2030, with some effect also from a change from water-intensive rice to wheat production, especially in China.

For the 93 countries taken together, the irrigation water withdrawals would increase from 8 percent in 1998 to 9 percent in 2030 if expressed as a percentage of annually renewable water resources. This statistic is of limited practical value where rainfall and river flows are highly variable. It is also another example of the fallacy of aggregation. In the Near East/North Africa region, irrigation withdrawal would increase from 40 to 53 percent of the renewable resource and in South Asia from 44 to 49 percent, compared with an increase of 1-2 percent in Latin America. The regions with withdrawals of more than 40 percent of their renewable water for irrigation present the greatest

Plate 4 Section of the left bank of the principle canal under construction at Bishenyi (Rwanda)

FAO/20232/FAO

challenge, especially as the differences are greater at the country level. Of the 93 countries, 10 (including Egypt and Pakistan) now withdraw more than 40 percent of their renewable water resources for irrigation, while another 8 (including India and China) abstract more than 20 percent of the renewable water for irrigation.

Although the IFPRI and FAO predictions differ in the details, they agree on the general direction of the expected changes. Closer agreement cannot be expected as the model outcomes depend on the underlying assumptions. A most important assumption is the extent to which water productivity in agriculture can be increased between now and 2025 or 2030.

INVESTMENTS IN IRRIGATION INFRASTRUCTURE

An accurate global view of irrigation investment trends does not exist, but certain proxies can be used to indicate such trends. For example, there has been a sharp decline in World Bank lending for new irrigation schemes (Jones, 1995). Funding for new irrigation construction has largely stopped and the emphasis is on the sustainability and efficiency of existing systems. According to Thompson (2001), irrigation and drainage is still one of the core investment activities of the World Bank's rural portfolio, but now mainly in support of rehabilitation and the devolution of responsibilities to water user associations (WUAs). However, the number of irrigation and drainage projects is expected to decrease to well below what it was in the 1980s. Investments in irrigation systems are perceived to have failed to address the changing needs of irrigation services because rehabilitation of existing systems was mostly carried out to restore original project objectives. This type of rehabilitation is often inappropriate as it tends to ignore desirable changes in cropping patterns and irrigation techniques and thus allows low water-productivity practices to continue. Cost and time overruns in irrigation projects as well as public opposition to large dam building projects have further eroded the confidence of funding agents in irrigation investments. Considering the negative aspects of irrigated agriculture (e.g. salinity, waterlogging, health hazards, and groundwater exploitation), it can no longer be taken for granted that irrigation is a protected, preferred practice and that its negative externalities will be accepted unconditionally. Nevertheless, irrigation development and dam building must continue, even if only to update existing facilities and to replace dams and reservoirs that have lost most of their storage capacity as a result of sedimentation. The loss of effective capacity of Mediterranean dams is currently between 0.5 and 1 percent/year with some as high as 3 percent (in Algeria). In Morocco, the reduction in regulating capacity attributable to reservoir silt-up is equivalent to a loss of irrigation potential of 6 000-8 000 ha/year (FAO, 2002d). Improved erosion control in catchment areas may eventually prolong the life span of reservoirs and dams.

A reduced level of investment in irrigation may not be all bad. In the past, the construction of many irrigation systems was supply driven as part of internationally funded development aid without significant input from the future users of the scheme and sometimes against their expressed wishes. Irrigation potential was and still is seen as an important indicator for evaluating future irrigation development. This parameter expresses how much a country's irrigated

Plate 5 Farmer checking rice crop during rice-cum-fish trials (Zambia)

FAO/17218/A. JENSEN

area could be expanded according to land use and water availability criteria. Hence, its value changes over time depending on the country's economy and competition for water. However, this notion of irrigation potential has often been used as the sole criterion in setting a country's agricultural and water resource policies, without a parallel analysis of economic, social, institutional and environmental constraints and without a thorough market analysis. The failure of some irrigation schemes can be attributed to a narrow focus on irrigation infrastructure and water distribution combined with an insufficient focus on the productivity of the agricultural systems and their responsiveness to agricultural markets (Burke, 2002).

The public policy of supply-driven irrigation development, adhered to by many governments and donor agencies, may be justified because of the observed importance of the role of irrigated agriculture in food security (below). However, the role of the private sector in irrigation development is often underestimated or ignored. The many investment decisions of smallholders and commercial farmers could exceed public investment, e.g. in Zambia (FAO, 2002e) and India (Moench, 1994). In particular, where there is a comparative advantage in irrigated production to service local and international markets, which may be for vegetables and cut flowers rather than traditional food crops, significant private irrigation investments appear to follow.

THE ROLE OF IRRIGATION IN POVERTY ALLEVIATION AND RURAL DEVELOPMENT

Since 1960, growth in average cereal yields has largely kept pace with the increase in world population. It is widely assumed that it will continue to do so until the population begins to stabilize. Most of the increase in grain production has been the result of yield increases rather than expansion in cropped area. Projections by FAO, the IFPRI and the World Bank assume that the further increases in cereal production will come from continuous increases in yield. However, trends in yield data collected by FAO indicate that the average world cereal yield would have to reach at least 4 tonnes/ha for a world population of 8 000 million people from its present level of about 3 tonnes/ha (Evans, 1998). At present, all the developed countries taken together have not achieved an average cereal yield of 4 tonnes/ha. This is the extent of the challenge.

The contribution from irrigated agriculture to achieving this goal will be critical as irrigation provides a powerful management tool against the vagaries of rainfall. Irrigation also makes it economically attractive to grow high-yielding crops and to apply the adequate plant nutrition and pest control required in order to obtain the full potential of these modern varieties. According to the IFPRI, while food production will increase much faster in developing countries than in developed countries, it will not keep pace with demand, and food imports will need to increase. In 1999/2000, developing countries produced 1 030 million tonnes of grain, i.e. 55 percent of world production, and accounted for 61 percent of world grain consumption. To bridge the gap between demand and production, developing countries imported 231 million tonnes of grain, equivalent to 72 percent of worldwide imports. These statistics illustrate that developing countries play a major role in the international agricultural trade and that they are highly susceptible to changes in the world agricultural market in terms of food security. For the poorest countries, an increase in domestic agricultural production is key to improving food security. This explains why expectations about the food security role of irrigated agriculture remain high (**Box 3**).

Agricultural development based on water conservation and irrigation is often considered a promising avenue for poverty alleviation in rural areas. For example, the availability of water for a small domestic garden plot, usually managed by women, can make a significant difference to household nutrition and thus contribute to improved livelihoods. Water harvesting may make this possible (FAO, 2002d). However, this effect is small scale and irrigated agriculture with its higher crop yields is expected to have greater impact on the incidence of poverty and malnutrition. This effect is expected regardless of whether the irrigation project is small or large scale. However, recent studies have shown that poverty alleviation as a result of irrigation development requires that the project be geared towards the needs of the poor (van Koppen *et al.*, 2002). This includes access to training in the technical aspects of irrigation but also in community organization and marketing. One of the recurrent problems is the lack of access to credit, capital or land. Even microcredits have no grace period;

Box 3 Water for food security in China *Source: Heilig* et al.*, 2000; Smil, 1996*

The question whether China can produce food for its growing population is controversial. Brown (1995) has suggested that the answer is no. One of the counterarguments is that China has more farmland than the government acknowledges officially. Another is that the official data underestimate crop yields by up to 50 percent for crops in hilly interior regions. The data are probably quite reliable for rice from the central and eastern provinces.

Water shortage is probably the single most important problem facing China's agriculture today. Water usage in China is predicted to rise by 60 percent by 2050, as an increasing proportion of the people live in cities. Water deficits may affect 36 percent of China's grain production, which is produced in areas that either depend totally on irrigation or have significantly higher production when irrigated. However, this also means that 64 percent of crop production is not threatened systematically by water shortages, either because it comes from fields in humid regions, or because precipitation is sufficient for some rainfed production. However, because of drought conditions, this production may not be attainable every year. Without irrigation and water management, paddy fields in the humid south can probably not produce their current two to three harvests but only one or two. However, in a large area in China's south and southeast, there is no water scarcity problem but a water scarcity challenge.

More efficient use of water and fertilizers combined with lower post-harvest losses would constitute the most important improvements in China's irrigated agriculture. The creation of WUAs has already contributed to ensuring a more regular, guaranteed supply of water to farmers, who then allocate water equitably through the associations. Other improvements could include improved production of pork, reliance on broilers to supply most of the additional demand for meat, expanded production of farmed fish, and increased consumption of dairy products. This combination can contribute considerably to meeting the country's future nutrition needs without requiring enormous imports of foreign grain.

repayments typically have to start after a few weeks. This makes them of little use for the purchase of cheap technology, such as treadle pumps and microdrip systems. It has been argued that these technologies are profitable within a short period and do not require a subsidized price for poor people or specific poverty alleviation measures (FAO, 2002d). The problem of credit is not specific to irrigation development and needs to be addressed in a more general sense for successful rural development of poor regions.

Expanding irrigated areas, increasing the control of water and applying high-yield technology in irrigated agriculture have given rise to large increases in farm income, especially in Asia. However, this increase has been disproportionately in the hands of the larger peasant farmers. They are not the poorest of the poor, but their increased expenditure pattern has driven increased employment of those who are the poorest of the poor. The latter have little or no land and they benefit little even from agricultural production programmes directed most closely to them. However, they benefit from lower food prices, increased wages and growth in demand for rural non-farm goods and services (FAO, 2002d; Mellor, 2001; Briscoe, 2001). By contrast, the capital- and import-intensive consumption patterns of large-scale farmers, and especially absentee farmers, contribute much less to poverty reduction. This is more typical for some Latin American countries than for Asia and Africa.

Cost recovery from poor farmers for the operation and maintenance (O&M) of irrigation systems is controversial. Subsidizing these services and providing irrigation water far below cost is financially unsustainable. Stepped tariffs in which the basic need is provided free to poor people may work in the case of drinking-water but is difficult to implement for irrigation water. Monitoring the efficiency of water use in agriculture for many small farmers each using a small amount of water is expensive, but providing irrigation water below cost contributes to wasting of water (FAO, 2002d).

In developing countries, agriculture generally produces many non-tradable goods, such as food crops of lower quality and goods with unusually high transaction costs. This aspect gives agriculture a prominent role in poverty reduction. It also buffers the national economy from shocks to international markets in agricultural commodities. For the rural poor in low-income countries, increased employment opportunities allow them to escape from poverty and hunger. Because they generally have few skills, the poor are more likely to find employment in the production of goods and services that cannot be marketed on the international market. Examples of this type of employment include maintenance of irrigation and drainage structures, watershed management, and afforestation, and where there is a sizeable storage reservoir, employment could be found in fisheries, ecotourism and navigation. Thus, increased employment and, hence, poverty reduction

Plate 6 Women watering cabbages in a vegetable garden with water drawn from a deep well (Mali)

FAO/13710/J. ISAAC

depend on increased domestic demand for these non-tradable, non-farm goods and services. Agriculture is the principle source of such demand and so it is only with rising farm incomes that poverty can be reduced and food security increased (FAO, 2001c).

Hence, investments in irrigation development may achieve additional goals such as enhancing economic growth and poverty alleviation in rural areas. Nonetheless, the question may be asked whether investments in other parts of the infrastructure are not more likely to achieve these goals. For example, the steady decline in poverty in India from the mid-1960s to the early 1980s was strongly associated with agricultural growth, particularly the green revolution, which coincided with massive investments in agriculture and rural infrastructure (Fan *et al.*, 1999). According to IFPRI studies in India, the impact of additional irrigation investments on poverty reduction ranked third after rural roads, and agricultural research and extension. Additional government spending on irrigation had a significant impact on productivity growth, but no discernible impact on poverty reduction. While spending on irrigation and power has been essential in the past for sustaining agricultural growth, the levels of irrigation may now be such that it may be more important to maintain rather than increase the systems. The IFPRI studies have also indicated that the marginal returns to several infrastructural investments in India are now higher in many rainfed areas. They also have a potentially greater impact on reducing rural poverty (Bhalla *et al.*, 1999).

A global analysis of the link between farming systems and poverty indicates that the prospects for reducing agricultural poverty in the Near East and North Africa are good (Dixon *et al.*, 2001). However, for the region as a whole, exit from agriculture is the best household strategy for poverty reduction, followed by increased off-farm income. The study indicates that the priority roles of the State are to support the development of vital infrastructure, such as roads, water supplies, services and power supply, and to regulate resource use and pricing for water and power. By comparison, in South Asia, measures that support households in small-farm diversification and also for growth in employment opportunities in the off-farm economy were found to be the most likely to contribute to poverty reduction.

When weighing the pros and cons of new irrigation investments against the benefits of other investments, all additional potential benefits of irrigation, such as health benefits resulting from better nutrition (i.e. more calories and a more balanced diet) and greater rural employment, should be taken into account. Many of the irrigation benefits are site-specific and generalizations cannot be made. Moreover, without proper techniques for monitoring the physical performance of irrigation systems, it is impossible to assess the potential benefits that may accrue from further investments to improve them. Notwithstanding these caveats, the fundamental question concerning the economic utility of further investments in irrigation development as a means towards rural development and poverty alleviation is an important one. At least two conclusions can be drawn from the discussion of the role of water in sustainable food production, poverty alleviation and rural development. The first is that donor agencies and governments have a difficult choice to make when investing for poverty reduction and rural development. The choice is not automatically for agriculture or water. The second conclusion is that the right set of government policies can make a large difference in food production, poverty reduction and rural development.

chapter 3

Why agricultural water productivity is important for the global water challenge

Productivity is a ratio between a unit of output and a unit of input. Here, the term water productivity is used exclusively to denote the amount or value of product over volume or value of water depleted or diverted. The value of the product might be expressed in different terms (biomass, grain, money). For example, the so-called 'crop per drop' approach focuses on the amount of product per unit of water. Another approach considers differences in the nutritional values of different crops, or that the same quantity of one crop feeds more people than the same quantity of another crop. When speaking of food security, it is important to account for such criteria (Renault and Wallender, 2000). Another concern is how to express the social benefit of agricultural water productivity. All the options that have been suggested can be summarized by the phrases 'nutrient per drop', 'capita per drop', 'jobs per drop', and 'sustainable livelihoods per drop'. There is no unique definition of productivity and the value considered for the numerator might depend on the focus as well as the availability of data. However, water productivity defined as kilogram per drop is a useful concept when comparing the productivity of water in different parts of the same system or river basin and also when comparing the productivity of water in agriculture with other possible uses of water.

Crop water production is governed only by transpiration. As it is difficult to separate transpiration from evaporation from the soil surface between the plants (which does not contribute directly to crop production), defining crop water productivity using evapotranspiration rather than transpiration makes practical sense at field and system level. In irrigated agriculture in saline areas, the leaching requirement, i.e. the amount of water that needs to percolate to maintain rootzone salinity at a satisfactory level, should also be included together with evapotranspiration in the amount of water that is necessarily depleted during plant growth. Other non-productive but beneficial uses could be included. Examples are evapotranspiration by windbreaks, cover crops, and the water used in wetting seedbeds to enhance germination.

The question of considering water losses from seepage and field percolation as consumption does not receive a unique response. If this water is of no use downstream or if it generates further pollution such as that resulting from geological salt leaching (e.g. San Joaquin Valley, California, the United States of America), then it must be accounted for as consumption. Solutions to minimize these losses, such as canal lining or water improvement application, then have a positive effect on productivity. However, from a broader environmental point of view, it can be important to consider the impact of the outflow of an irrigation system on the overall productivity of an ecosystem.

As with the numerator, the choice of the denominator (which drops to be included) should depend on the scale, the point of view and the focus. At basin level, the choice might be between water diverted from the source and the same minus water restored, whereas at field level one might consider useful rain, irrigation water and supplemental irrigation.

SPATIAL VARIABILITY OF WATER PRODUCTIVITY

Reported data on water productivity with respect to evapotranspiration (WP_{ET}) show considerable variation, e.g. wheat 0.6-1.9 kg/m^3, maize 1.2-2.3 kg/m^3, rice 0.5-1.1 kg/m^3, forage sorghum 7-8 kg/m^3 and potato tubers 6.2-11.6 kg/m^3, with incidental outliers obtained under experimental conditions. Data on field-level water productivity per unit of water applied (WP_{irrig}), as reported in the literature, are lower than WP_{ET} and vary over an even wider range. For example, grain WP_{irrig} for rice varied from 0.05 to 0.6 kg/m^3, for sorghum from 0.05 to 0.3 kg/m^3 and for maize from 0.2 to 0.8 kg/m^3. The variability occurs because data were collected in different environments and under different crop management conditions. These affected the yield and the amount of water supplied (Kijne *et al.*, forthcoming). Furthermore, it is often difficult to determine the real crop yield over a large area, e.g. the size of a large irrigation system. When asked for yield figures, individual farmers are likely to give a figure that depends on the situation. For a loan application, they may overstate the yield, whereas for payment of a debt or a tariff, they will probably understate the yield

Plate 7 A farmer works on an irrigation canal (Mexico)

FAO/18609/G. BIZZARRI

obtained. Vegetable yields of vegetables may change every day, and unless good records are kept, no one will know exactly how much was harvested during the total harvest period. Yields expressed in monetary terms are more doubtful as prices on the local market may fluctuate considerably over time (FAO, 2002d).

Nevertheless, water productivity data across scales are useful in assessing whether water drained from upstream is reused effectively downstream. However, there are few reliable data on water productivity at different scale levels within the same system. A study using remote sensing and GIS technologies assessed crop WP_{ET} at various irrigation system scales in the Indus Basin in Pakistan (Bastiaanssen *et al.*, 2003). Crop water productivity was found to vary significantly at the scale of small canal command areas. When water productivity was aggregated for canal command areas, the highest water productivity values decreased gradually. Their variability also decreased until at a scale of about 6 million ha water productivity tended to a low value of about 0.6 kg/m^3. This arose because at the larger scale, canal commands with less fertile or saline soils and with less canal water and poorer quality groundwater were included in the average.

Box 4 presents data illustrating the productivity of water in economic terms.

THE SUBSTANTIAL INCREASE OF WATER PRODUCTIVITY IN AGRICULTURE

Despite concerns about the technical inefficiency of water use in agriculture, water productivity increased by at least 100 percent between 1961 and 2001. The major factor behind this growth has been yield increase. For many crops, the yield increase has occurred without increased water consumption, and sometimes with even less water given the increase in the harvesting index. Example of crops for which water consumption experienced little if any variation during these years are rice (mostly irrigated) and wheat (mostly rainfed), for which the recorded increases worldwide amount to 100 and 160 percent respectively. At the global level, the increase in water consumption for agriculture

Box 4 Water productivity in economic terms *Source: Merrett, 1997; Molden* et al.*, 2001*

Data are available for agricultural water productivity in economic terms for Jordan. Water productivity ranged from US\$0.3/m^3 for potato to US\$0.03/m^3 for wheat. The average value for agricultural products was US\$0.19/m^3 and for industrial products US\$7.5/m^3. The IWMI analysed economic water productivity data from two irrigation systems in South Asia. The values for wheat production ranged from US\$0.07 to 0.17/m^3. Average systemwide water productivity values of US\$0.10 and 0.15/m^3 were reported for two other systems in South Asia. Systemwide values for a total of 23 irrigation systems in 11 countries in Asia, Africa and Latin America ranged from US\$0.03/m^3 (for a system in India) to US\$0.91/m^3 (for one in Burkina Faso), with an overall average of US\$0.25/m^3. Comparison with the most recent cost of about US\$0.50/m^3 for desalinated seawater illustrates that this source of water is too expensive for virtually all agricultural production. However, its cost has come down to about one-tenth of what it was 20 years ago. Further improvements in the technology of seawater desalination are likely. Its cost is also likely to continue falling provided that as energy remains cheap.

in the past 40 years has been 800 km^3 (Shiklomanov, 2000) while world population has doubled to 6 000 million. Considering that the arable rainfed area has not increased, one can conclude that with an additional 800 km^3 of water the world has been able to feed an additional 3 000 million people. This gives a rough estimate of 0.720 m^3/d/capita. This figure is low compared to the estimated global average for 2000 of 2.4 m^3/d/capita, which includes water for food at field level not including water losses. This is a good indicator of the significant productivity gain recorded in agriculture; a gain that has enabled the world to accommodate the doubling of the population and also increase intake.

As a whole, one can estimate that the water needs for food per capita halved between 1961 and 2001 from about 6 m^3/d to less than 3 m^3/d (Renault, 2003).

The importance of water needs for food makes any small relative gain in this sector equivalent to a significant gain for other uses. For example, given the water needs for capita in 2000, a 1-percent increase in water productivity in food production generates a potential of water use of 24 litres/d/capita. In order to produce the equivalent of the domestic water supply, a gain of 10 percent in agricultural water productivity would be required, which is a matter of years. Therefore, it can be argued that investing in agriculture and in agricultural water is the best avenue for freeing water for other purposes.

However, future agricultural gains will need to be split into several components: (i) compensation for the reduction of agricultural production areas as a result of urban encroachment, soil degradation, and the depletion of water resource availability or access (groundwater); (ii) increased water access for the rural poor and vulnerable groups; (iii) generation of wealthier farming systems; and (iv) freezing water for other uses including the environment.

KEY PRINCIPLES FOR IMPROVING WATER PRODUCTIVITY

The key principles for improving water productivity at field, farm and basin level, which apply regardless of whether the crop is grown under rainfed or irrigated conditions, are: (i) increase the marketable yield of the crop for each unit of water transpired by it; (ii) reduce all outflows (e.g. drainage, seepage and percolation), including evaporative outflows other than the crop stomatal transpiration; and (iii) increase the effective use of rainfall, stored water, and water of marginal quality.

The first principle relates to the need to increase crop yields or values. The second one aims to decrease all ‘losses’ except crop transpiration. Its phrasing does not imply that it will be impossible to increase water productivity by reducing stomatal transpiration. It is conceivable that plant breeding may find ways to overcome this constraint. The third principle aims at making use of alternative water resources. The second and third

Plate 8 Food transfer can be considered equivalent to transfer of “virtual water” (Somalia)

FAO/20430/A. PROTO

principles should be considered parts of basinwide integrated water resource management (IWRM) for water productivity improvement. IWRM recognizes the essential role of institutions and policies in ensuring that upstream interventions are not made at the expense of downstream water users.

These three principles apply at all scales, from plant to field and agro-ecological levels. However, options and practices associated with these principles require different approaches and technologies at different spatial scales.

ENHANCING WATER PRODUCTIVITY AT PLANT LEVEL

Plant-level options rely mainly on germplasm improvements, e.g. improving seedling vigour, increasing rooting depth, increasing the harvest index (the marketable part of the plant as part of its total biomass), and enhancing photosynthetic efficiency. The most significant improvements in yield stability have usually resulted from breeding programmes to develop an appropriate growing cycle such that the duration of the vegetative and reproductive periods are well matched with the expected water supply or with the absence of crop hazards. Planting, flowering and maturation dates are important in matching the period of maximum crop growth with the time when the saturation vapour pressure deficit is low. The periods of maximum crop growth may be optimized by means of breeding technology. Improved varieties with a deeper rooting system contribute to drought avoidance and the effective use of water stored in the soil profile. Drought escape and increasing drought tolerance are also important strategies for increasing water productivity (**Box 5**). Daylength-insensitive

Box 5 Real impacts of virtual water on water savings

Source: Renault, 2003; Zimmer and Renault, 2003

Exchanges of virtual water through food trade first captured the attention of experts in the Near East, where water is scarce (Allan, 1999) and imports represent considerable water savings. The value of virtual water of a food product is the inverse of water productivity. It is defined as the amount of water per unit of food that is or would be consumed during its production process.

Virtual water trade generates water savings for importing countries. It also generates global real water savings because of the differential in water productivity between the producing and the exporting countries. For example, transporting 1 kg of maize from France (taken as representative of maize exporting countries for water productivity) to Egypt transforms an amount of water of about 0.6 m^3 into 1.12 m^3, which represents globally a real water saving of 0.52 m^3 per kilogram traded. In 2000, the maize imports in Egypt and the related virtual water transfer thus generated a global water saving of about 2 700 million m^3. The global real water saving is significant: a first estimate shows that water savings from virtual water transfer through food trade amounts to 385 000 million m^3 (Oki *et al.*, 2003).

Food storage also generates real water savings. For example, in the Syrian Arab Republic, 1988 was a good year for the cereal production with yields of 1.6 tonnes/ha, leading to a surplus. Thus, 1.9 million tonnes of cereals were stored during that year. The following year was very dry, and the cereal yield dropped to 0.4 tonnes/ha. About 1.2 million tonnes of cereals were then withdrawn from storage to complement internal production and imports. Based on the water productivities recorded for these years (Oweis, 1997), the estimated value of virtual water was to 1 and 3.33 m^3/kg respectively. Therefore, the use of 1.2 million tonnes of cereals from storage in 1989 is equivalent to 4 000 million m^3 of virtual water. For the two-year period of reference (1988-89), some 2 800 million m^3 of water was saved by the food storage capacity.

Globally, the trade in virtual water is rising rapidly. It increased in absolute value from about 450 km^3 in 1961 to 1 340 km^3 in 2000, reaching 26 percent of the total water required for food including equivalence for sea products and sea fish. This value is shared evenly between energy, fat and protein products.

varieties of short to medium duration (90-120 d) enabled crops, such as wheat, rice and maize varieties developed as part of the green revolution, to increase water productivity by escaping late-season drought that adversely affects flowering and grain development. The modern rice varieties have about a threefold increase in water productivity compared with traditional varieties (Tuong, 1999). Progress in extending these achievements to other crops has been considerable and will probably accelerate following the recent identification of the underlying genes (Bennett, 2003). Genetic engineering, if properly integrated in breeding programmes and applied in a safe manner, can further contribute to the development of drought tolerant varieties and to increasing the water use efficiency.

RAISING WATER PRODUCTIVITY AT FIELD LEVEL

Improved practices at field level relate to changes in crop, soil and water management. They include: selecting appropriate crops and cultivars; planting methods (e.g. on raised beds); minimum tillage; timely irrigation to synchronize water application with the most sensitive growing periods; nutrient management; drip irrigation; and improved drainage for water table control.

Water depletion occurs when water evaporates from moist soil, from puddles between rows and before crop establishment. All cultural and agronomic practices that reduce these losses, such as different row spacings and the application of mulches, improve water productivity. The irrigation

Plate 9 Model of integrated fish farm. Combination of fish ponds with ducks (Lao People's Democratic Republic)

FAO/20906/K. PRATT

method also affects these evaporative losses. Drip irrigation causes much less soil wetting than sprinkler irrigation. The significance of soil improvement in enhancing water productivity is often ignored. However, integrated crop and resource management practices, such as improved nutrient management, can increase water productivity by raising the yield proportionally more than it increases evapotranspiration. This principle applies to both irrigated and rainfed agriculture. Integrated weed and integrated pest management have also contributed effectively to yield increases.

One of the field-level methods for increasing water productivity is deficit irrigation, where deliberately less water is applied than that required to meet the full crop water demand. The prescribed water deficit should result in a small yield reduction that is less than the concomitant reduction in transpiration. Therefore, it causes a gain in water productivity per unit of water transpired. In addition, it could lower production costs if one or more irrigations could be eliminated. For deficit irrigation to be successful, farmers need to know the deficit that can be allowed at each of the growth stages and the level of water stress that already exists in the rootzone. Most importantly, they need to have control over the timing and amount of irrigations. Deficit irrigation carries considerable risk for the farmers where water supplies are uncertain, as is the case with rainfall or unreliable irrigation supplies. Where water availability falls below a certain level, the value of the crop can fall to zero, either because the crop dies or because the product is of such low quality as to be unmarketable. When water is scarce, farmers could reduce the irrigation as appropriate to maximize returns to water if they have control over the timing and amount of irrigations.

This degree of flexibility is usually the case with sprinkler and drip irrigation, and also with pumped groundwater if the farmer owns the pump. A totally flexible delivery system for surface irrigation in large irrigation systems is expensive because of the required overcapacity in the conveyance system.

The trade-off between reduced yield and higher water productivity needs to be quantified in economic terms before recommending deficit irrigation (and other water-saving irrigations in rice production).

The often cited low water productivity per unit of water supply in rice cultivation derives from considering as losses the percolation resulting from the standing water layer on the field surface. However, this water is often recycled, and rice water productivity generally compares well with that of a dry cereal. Nevertheless, water-saving irrigation techniques such as saturated soil culture and alternate wetting and drying can reduce the unproductive water outflows drastically and increase water productivity. These techniques generally lead to some yield decline in the current lowland rice high-yielding varieties (**Box 6**). However, some experiments are reporting substantial yield increases for local varieties (Deichert and Saing Koma, 2002) using a technique called system rice intensification (SRI), a technique which originated in Madagascar (de Laulanié H., 1992). Here again there is no unique response; the fit with local resources and capacity is the most important feature to account for. Without anticipating results of current investigations in many countries, it seems that the potential of the SRI technique for the poor to increase the productivity of scarce land and water is significant provided that enough family labour is available. Other approaches are being researched as part of efforts to increase water productivity without sacrificing yield. One of these is to develop so-called aerobic rice systems that allow rice cultivation in non-flooded conditions. The development of these new rice varieties is essential if rice is to be grown like other irrigated upland crops and the deep percolation associated with paddy rice is to be avoided.

Box 6 Water-saving irrigation technologies in rice production *Source: IRRI, 2002*

Exploring ways of producing more rice with less water is essential for food security in Asia while also protecting the environment. The International Rice Research Institute (IRRI) has studied various field-level water-saving technologies, e.g. alternate wetting and drying; SRI; saturated soil culture; aerobic rice; and ground-cover systems. Each of these techniques reduces one or more of the unproductive water outflows (e.g. seepage, percolation, and evaporation) and hence increases water productivity. However, they also introduce periods in which the soil is not flooded or not even saturated, which usually leads to yield decline. Recent results from northern China and the Philippines indicate that with current germplasm and management technologies, aerobic rice yields are about 40 percent lower and reduce water requirements by about 60 percent compared with flooded lowland systems.

The shift from flooded systems to partly aerobic (non-saturated) conditions also has profound effects on soil organic matter turnover, nutrient dynamics, carbon sequestration, weed ecology and greenhouse gas emissions. Whereas some of these changes are positive, others, such as the release of nitrous oxide and the decline in organic matter, are perceived as negative effects. The challenge is to balance the negative and positive effects through the development of effective integrated water-saving technologies that can ensure the sustainability of rice-based ecosystems and environmental services.

Box 7 A soil and water conservation project in Burkina Faso *Source: Oweiss* et al.*, 1999*

Until the early 1980s, most soil and water conservation projects in Burkina Faso had failed dramatically. From 1962-65, heavy machinery was used to treat entire catchments in the Yatenga Region of the country's Central Plateau with earthen bunds. Although the project, which treated 120 000 ha in 2.5 dry seasons, was well-conceived technically, the land users were not involved, and they were not at all interested in what had been constructed. From 1972-1986, several donor agencies funded a soil and water conservation project based on a more participatory approach. However, once again, the land users were not willing to maintain the earth bunds because of the high maintenance requirement, lack of benefits and other reasons. As a result, most of the bunds had disappeared entirely after 3-5 years.

An NGO-supported agroforestry project (1979-1981) in the Yatenga Region tested a number of simple soil and water-conservation/water-harvesting techniques and asked the villagers to evaluate the techniques. They expressed a preference for contour stone bunds. The project also initiated training programmes at village level that taught farmers how to use a water tube level, so enabling them to determine contour lines more accurately. In the Yatenga and other parts of the Central Plateau, tens of thousands of hectares have now been treated with contour stone bunds.

The main reason why the farmers adopted contour stone bunds and improved traditional planting pits (a technique developed by a local farmer in which water and fertilizers are mixed together) is that they produced immediate and substantial yield increases. On land that is already cultivated, the construction of the contour stone bunds is estimated to increase yields by 40 percent.

Water-related problems in rainfed agriculture are often related to large spatial and temporal rainfall variability rather than low cumulative volumes of rainfall. The overall result of rainfall unpredictability is a high risk for meteorological droughts and intraseasonal dry spells (Rockström *et al.*, 2003). Bridging crop water deficits during dry spells through supplementary irrigation stabilizes production and increases both production and water productivity dramatically if water is applied at the moisture-sensitive stages of plant growth.

Water harvesting for agriculture involves a storage reservoir, while in runoff farming the collected runoff is applied directly to the cultivated area. Either way, the investments in the construction of the ditches that take the runoff to the storage reservoir and of the reservoir itself are relatively small. Maintaining these structures may be more difficult if heavy rains periodically wash them away. Many factors affect the success of rainwater harvesting. These include: the method used for runoff collection and storage; the topography; the soil characteristics (especially the infiltration rate); the choice of crop to be planted; fertilizer availability; and the effectiveness of the soil crust in the catchment area. However, probably more important than any of these physical parameters is the involvement of the beneficiaries in the design and implementation of the water harvesting structures (**Box 7**).

Socio-economic assessments of water harvesting and supplementary irrigation are rare. It is recognized that sustainable increases in water productivity by water harvesting can only be achieved through a combination of farmer training, water conservation, supplementary irrigation, better crop selection, improved agronomic practices, and political and institutional interventions. Planning (and economic assessment) should consider explicitly the short-term effect and

Plate 10 Members of the village committee of Ankofafa protecting a maize field (Madagascar)

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longer-term implications of hydrological changes brought about by water harvesting on downstream water users.

This paper has mentioned a number of practices that have the potential to enhance water productivity. The question now is one of how to stimulate the adoption of these techniques and their adaptation for local conditions. The importance of farmer participation and empowerment through the organization of WUAs in irrigation management is well accepted and they are widely established. However, less well known is the feasibility and advantage of using the same form of farmers' associations for the purpose of introducing collectively improved cultural practices, such as minimum tillage or raised beds. Adoption of a range of water-productivity-enhancing practices by a large number of individuals should be stimulated through community-level interventions in order to ensure that opportunities to divert unallocated water to other productive uses are not missed.

ACCOUNTING FOR WATER PRODUCTIVITY AT SYSTEM AND BASIN LEVEL

Changing the focus from the field level to system and river-basin level changes the relative importance of the various water management processes. At the larger scale, the effect of agriculture on other water users, human health and the environment becomes at least as important as production issues.

Options for improving water productivity at the agro-ecological or river-basin level are found in: better land-use planning; better use of medium-term weather forecasts; improved irrigation scheduling to account for rainfall variability; and conjunctive management of various sources of water, including water of poorer quality where appropriate. Therefore, integrating germplasm improvement and resource management is crucial in the enhancement of water productivity at the field scale and above.

Gains in water productivity are possible by providing more reliable irrigation supplies, e.g. through precision technology and the introduction of on-demand delivery of irrigation supplies (Chapter 6). However, an increase in water productivity may or may not result in greater economic or social benefits. The social benefits represent the benefits to society resulting from the water-productivity-enhancing interventions. Water in the rural areas of developing countries has many uses. Thus, water is both a public and a social good, a fact that complicates value calculations. These many uses of water include: the production of timber, firewood and fibre; and raising fish and livestock. Non-agricultural uses of water include domestic (drinking and bathing) and environmental uses.

An IWMI study of an irrigation system in Kirindi Oya in southern Sri Lanka illustrates the importance of the multiple roles of water in agriculture (Renault *et al*., 2000). The study found that at system level crops consumed only 23 percent of the total water supply, including both rainfall and external irrigation water. Of the remainder, 8 percent was used for grazing land, 6 percent evaporated from the reservoir, 16 percent was lost to the sea, 3 percent drained into lagoons, while as much as 44 percent of the water supply went to perennial vegetation that had developed since the construction of the scheme. This perennial vegetation was there because of irrigation seepage and recharge of the shallow groundwater. Tree growth is important to the people living in the area as it provides them with shade and thus improves their environment. In this project, as well as in many places in southern India, it also provides income from coconut and materials for construction (beams and ropes). Other trees are important for additional nutritional values (fruits) and some are crucial for their medicinal properties. A changeover to total control of irrigation outflow in order to increase water productivity would cause the collapse of the entire local agroforestry system (FAO, 2002d).

Another example of the economic and social benefits of agroforestry is a project located along the Niger River in Mali. In this project, trees were planted on the bunds of rice fields, and also in the middle of the rice fields without affecting rice yields adversely. In this remote arid part of Mali, the value of the wooden poles of seven-year-old eucalyptus trees was so high that the farmers could pay for the O&M of the irrigation system from the sale of the trees. In another irrigation system, in southwest Burkina Faso, oil-palm and fruit trees were combined successfully with irrigated crops (mainly maize, groundnuts and industrial tomatoes). Trees were planted on ridges or on the boundaries between parcels. On the sandy, percolating soils of the irrigation system, the trees produced an important amount of

Box 8 Benefits from traditional floodplain agriculture compared with large-scale irrigated agriculture

Source: IUCN, 2000

The estimated value of the Hadejia-Jama'ara floodplain use in northern Nigeria indicates that traditional practices provide higher benefits than crops grown on the Kano irrigation project. Benefits derived from firewood, recession agriculture, fishing and pastoralism were estimated at US$12/litre of water, compared with US$0.04/litre for benefits from the irrigation project. This evaluation is important for the region as more than half of the floodplains have been lost to drought and upstream reservoirs.

Even without accounting for such services as wildlife habitat, the wetland is more valuable to more people in its current state than after conversion to large-scale irrigated agriculture.

complementary food and income, while the impact on the main crop was minimal (FAO, 2002d). **Box 8** presents a case where traditional agriculture had greater benefits for society than did large-scale irrigation.

These examples point out that not all measures to increase water productivity are appropriate in all circumstances. It is essential to consider the various uses of water in agriculture before measures are introduced that would increase water productivity at the expense of other benefits from the same source of water, especially those benefits that accrue to the local poor and landless people.

POLICY TOOLS FOR PROMOTING WATER PRODUCTIVITY GAINS

Using price policies to promote the economic productivity of water requires significant government intervention in order to ensure that equity of access to water and public-good issues are covered adequately (Barker *et al.*, 2003; Rogers *et al.*, 2002). Some studies in the Indian subcontinent and elsewhere have suggested that the price for water that would be required to affect demand substantially would be about ten times the charge required to cover the O&M of the irrigation system. A charge sufficient to cover O&M would have a minimal effect on water demand. Moreover, introducing volumetric charges for irrigation water is difficult and involves considerable expense for the installation of measuring structures and for fraud prevention (Perry, 2001). Last, in most rice-based systems in Asia, volumetric charging at individual user level or even group level is unsuitable given the permanent overflow and recycling water flows throughout the command area.

The groundwater market in India illustrates the perhaps unintended impact of government policies on the availability of water to farmers and others. Farmers in Gujarat paid about four times as much for pumped groundwater compared with farmers in Punjab and Uttar Pradesh. This difference was attributed to: (i) differences in the way farmers were charged for the electric power to run their pumps (flat rate versus per unit consumed); (ii) the tubewell spacing policy in Gujarat that gave each tubewell owner a monopoly over some 203 ha; and (iii) the scarcity of public tubewells in Gujarat, which also reduced competition among groundwater suppliers. The high prices for tubewell water in Gujarat discriminated against small and poor farmers. However, some simple changes in water policies for power pricing, tubewell spacing and public tubewells could transform groundwater markets in Gujarat into powerful instruments for small-farmer development (Shah, 1985).

Aiming for the highest economic productivity of water in agriculture may conflict with the political desire for national food security. More often than not, the economic productivity of water in growing staple crops is less than that for growing vegetables or flowers for export markets. Crop substitution involves switching high water-consuming crops for less water-consuming crops or for crops with higher economic productivity. The approach provides a strategy for increasing crop water productivity at the agro-ecological system level as well as at the global level (**Box 5**).

Policies and incentives are important in the adoption of changes from traditional agronomic and cultural practices (FAO, 2001a). However, it is necessary to identify the types of policies and incentives that will work best. Experience with conservation agriculture indicates that the short-term interests of the farmers often differ from the long-term interests of society and that the financial benefits that accrue from changes in cultural practices often take a long time to materialize. In addition, although there are large differences between individual farms, external factors also play a role, e.g. the transmission of information (via policy-related activities and social processes). Of particular importance is the fact that the inconsistent and sometimes contradictory results from studies on the adoption of new practices suggests that the decision-making process is highly variable. This decision-making process needs to be understood more fully as it will affect the lead time from study to field practice. This lead time is often unacceptably long considering the urgent character of water-scarcity problems. Experience from participatory research and extension could help reduce this lead time.

chapter 4

Risk management in agricultural water use

THE NATURE OF RISK

Vulnerability to drought varies from country to country. It depends *inter alia* on the stage of development. Economies in the early stages of transition from subsistence farming to a more modern and productive farm economy are particularly vulnerable. This applies to much of rainfed agriculture. Rainfall patterns over Africa have not changed significantly in the past century. In particular, the Sahel, the Horn of Africa and the countries around the Kalahari Desert are characterized by high interannual and intraseasonal rainfall variability. Good and bad years do not occur at random but tend to be grouped. This has important implications for food security as food and water must be stored over a period of several poor years.

Risk is defined as the product of hazard and vulnerability. In other words, it relates to the probability of a damaging event, such as drought, and the foreseeable consequences of such an event. The risk of war and the resulting food insecurity are difficult to predict and this paper will not consider them further. In terms of agriculture, the most common risk is drought. On a global scale, this risk is much greater than that of cyclones, floods and storms. However, on a regional rather than global scale, there are areas where the risk of flooding exceeds that of drought. Drought represents one of the most important natural triggers for malnutrition and famine. Drought events can be addressed at the parcel level by several management decisions, at the watershed level and at the country level. The first decisions belong to farmers or farmers collectivities whereas decisions at watershed and country level must be taken by governments or state agencies.

According to Gommes (1999), risk is also defined more simply as a loss due to a damaging event. The advantage of this definition is that it can be materialized and measured easily (e.g. loss of agricultural production, loss of income). An acceptable risk is one that individuals, businesses or governments are willing to accept in return for perceived benefits. Local governments usually define the level of acceptable risk by considering information on drought hazards and combining it with economic, social and political factors specific to the area threatened.

Conflict is an ever-present risk and one of the most common causes of food insecurity. The displacement of people and the disruption of agricultural production and food distribution leaves tens of millions of people at risk of hunger and famine. Conversely, food insecurity may lead to or exacerbate conflict (FAO, 2002a).

According to FAO, conflict in sub-Saharan Africa resulted in losses of almost US$52 000 million in agricultural output between 1970 and 1997, a sum equivalent to 75 percent of all official development assistance received by the conflict-affected countries. Conflict combined with drought has triggered six of the seven major African famines since 1980. Early warning and response can prevent famine arising from drought and other natural disasters. In war zones, lack of security and disruption of transport and social networks impede delivery of relief aid. However, several other factors contribute to food insecurity. These include: lawlessness; lack of democracy; ethnic and religious divisions; degradation or depletion of natural resources; and population pressure (FAO, 2002a).

RISK MANAGEMENT STRATEGIES FOR AGRICULTURE

Stemming from the definition of risk, there are two major ways of minimizing risk, either by reducing hazard or by reducing the vulnerability. Ways of minimizing hazards are few and can include: rainmaking; avoidance of hail; and watershed management to content floods. Ways of minimizing vulnerability can include: development of surface (including pumping water from streams) and underground irrigation facilities; integrated management of water resources; ecosystem development and diversification; education and training of farmers; early warning systems; seasonal climate forecasting; and crop insurance.

Early warning systems and seasonal weather forecasts are increasingly available to provide timely information so that governments and international aid agencies

Box 9 Application of climate information *Source: Sarachik, 1999; Hansen, 2002; Ingram* et al.*, 2002*

An application of climate information is the use of that information to change or influence a decision regarding future actions. It is not possible to predict the future climate with absolute certainty. For this reason, predictions are expressed in terms of probability of occurrence. As with any probabilistic scheme, significant benefits can be realized only over a long sequence of trials. The need to think and act in terms of probabilistic strategy is one of the greatest obstacles to the applications of forecast information.

As public goals may have many aspects, it is often unclear what is being optimized by the application of climate information, and for which subset of the public. An example is the management of public water resources, where priorities of water quality, recreational use, the desirability of avoiding floods and the needs of the agriculture sector often come into conflict with one another. Interviews with water managers indicate that climate information is rarely used even where it is readily available. One reason for reluctance on the part of decision-makers may be the risk involved in taking novel actions that may not be successful. The penalties that might result from failure could seem to outweigh the potential gains.

While water managers may be interested in total seasonal rainfall, farmers have expressed more interest in receiving forecasts of the onset and end of the rains, and whether there would be dry spells during the rainy season. An issue of concern in disseminating climate forecasts to farmers is how to avoid potential disaster that could arise if the forecast is ‘incorrect’. Strictly speaking, a probability forecast is neither correct nor incorrect. Nonetheless, farmers might invest resources in response to a forecast that predicts a greater probability of higher than normal rainfall, and then lose their investment and more if rainfall is less than normal. These barriers to the adoption of climate information by water managers and farmers alike will only be surmounted as predictions are demonstrated to be successful.

can take the necessary measures to reduce the impact of drought. However, seasonal forecasting skills are imperfect and the forecasts are not yet available to farmers (FAO, 2002d). If they were, those forecasts could help farmers in choosing less water-demanding crops, e.g. sorghum rather than maize, when a drought is predicted (**Box 9**).

In the absence of reliable information about expected seasonal rainfall, some farmers will tend to accept risk in anticipation of greater profit, while others will tend to avoid risk even if there is a potential for high profit. Such risk avoidance or acceptance is a personal and a cultural characteristic.

The historical evolution of irrigated agriculture was a response to reduce the risk of crop failure in lands that were subject to periodic droughts, such as the basins of the Euphrates and Tigris rivers. The preceding chapters mention many field-level cultural and agronomic practices that could alleviate the impact of drought and thus reduce the risk of crop failure and food insecurity.

Crop practices and field management provide several means for coping with soil water management (Gommes, 1999). Strategies in rainfed agriculture are based on producing more food per unit of rainfall in a durable manner by collecting the maximum amount of rainfall at community, farm and parcel levels, minimizing water loss at farm and parcel levels, and using water efficiently at parcel level. The collection of maximum rainfall may involve both state and farmer organizations (water harvesting, use of recycled water from other sectors) or farmers alone (water harvesting at the farm, runoff reduction at parcel level, early planting, fallow cropping system, etc.). Minimizing water loss involves farmers (evaporation reduction by mulching or rapid crop cover, windshields, minimum tillage, weeding, etc.). The efficient use of water requires farmers' involvement (use of low water consuming crop species, adapted fertilization to available water, disease and pest control, optimal planting and seeding, selected varieties able to accomplish their cycle within the climate growing period, etc.).

Risk may be reduced substantially, while expected profit is reduced relatively less, by choosing combinations of alternatives rather than any single alternative. For example, a farmer in a rainfed area, such as Machakos in Kenya, where on average a crop of maize may yield well in one out of four years, could choose to seed one-quarter of a field with maize every year. The reality is more complicated as both the total seasonal rainfall and its distribution during the growing season have a large effect on crop yield.

The above strategies enable improved use of the available water at the parcel level. Moreover, traditional farming aims at a stable production rather than a maximum income. Farmers achieve this objective through diversification of production and low-input practices that provide that do not entail too much investment or cash. Association between farmers, for example at the village scale or within farmer groups, can further reduce the risk of low production.

SPREADING RISK

Crop insurance constitutes the most explicit risk-spreading mechanism that helps distribute the cost of weather-related events through financial institutions among other economic sectors and governments. Successful examples include crop insurance for the impact of cyclones and hailstorms. The impact of drought is greater in developing countries than in developed countries, but farmers in developing countries have at best only limited access to insurance. The cost of insurance for relatively low-value staple crops is usually unaffordable (FAO, 2002d).

However, spreading risk can also lead to water sharing. Water transfers within countries have occurred for some time. Some canals were constructed for navigational reasons, others to supply drinking-water to water-scarce cities, and others for agricultural purposes or various combinations of these causes. Well-known examples include the Snowy Mountain Scheme in Australia and various aqueducts in California, the United States of America. Internationally, an extensive system of link canals between the branches of the Indus River was constructed in order to ensure equity of water access between India and Pakistan following partition in 1947. China is developing extensive water transfer schemes linking the south of the country to the water-scarce and populous north. Funding and implementing such expensive schemes in the future may help to reduce the risk of international conflict over water. Where several countries share water resources, e.g. in the river basins of the Mekong, Nile, Euphrates and Tigris, there is a perceived risk that the combination of population growth, poverty, food insecurity and water scarcity might lead to conflicts over water. Current attempts at mediation through the establishment of river basin authorities aim to reduce these risks.

Plate 11 View of country side (Cambodia)

FAO/19680/G. BIZZARRI

chapter 5 Alleviating the environmental impact of agricultural water development

DEALING WITH EXTERNALITIES

Most production systems, agriculture included, can cause both positive and negative side-effects, or externalities that are not accounted for in markets. Agriculture's positive and negative environmental services are unintended consequences of market activities that have an impact on people other than the producer of the effect. These by-products tend not to be priced in the market and, hence, their economic values are unknown or difficult to assess. Consideration of all the positive externalities of agriculture is not readily possible. There are cases where the same phenomenon may be positive in certain circumstances and negative in others, or it may be valued positively by some observers and negatively by others. A positive externality may reduce a negative one, and vice versa. In addition, positive and negative externalities are often linked closely, e.g. soil salinity and improved employment opportunities in irrigated agriculture. Moreover, positive externalities are often ignored whereas negative ones tend to be reported widely. A well-known example of a negative externality is the loss of biodiversity as a result of draining wetlands for agriculture (FAO, 2002d). Such losses are accelerating as human settlement continues to impinge upon wetlands and forests (**Box 10**).

Many agricultural systems have become efficient transformers of technologies, non-renewable inputs and finance. They can produce large amounts of food, but have substantial negative impacts on capital assets (Pretty, 1999). These assets comprise not only the natural resources of soil and water per se but also nutrient cycling and fixation, soil formation, biological control, carbon sequestration and pollination. The issue raises concerns about what constitutes success in agricultural production if large yield increases come at the cost of environmental and health problems. One problem is that the benefits

Box 10 Developing river water resources: the case of the Senegal River

Source: FAO, 2001b

The Senegal River illustrates the complexity of valuing environmental externalities. When river dams were managed for hydropower development, the environmentally and socially sustainable production from floodplains was affected negatively. Conventional management of large dams ended the annual flooding on which such production systems depended. The river water was henceforth retained in an upstream reservoir and only released depending on the demand for power generation. This change in ecosystem functioning has not only led to the loss of traditional agricultural production systems, but also to that of local and migrant biodiversity that depended on the extensive floodplains at the fringe of the desert. There are ample examples of the need to compensate people who are relocated forcibly from the reservoir area. However, little is known about compensation for those downstream inhabitants who are not forced to relocate but who cannot maintain their pre-dam production systems.

Plate 12 Tuaregs and Bellas preparing soil for planting bourgou (Mali)

FAO/11604/J. VAN ACKER

and costs accrue to different people and are not measured in the same units. In the 1970s and 1980s, some people considered energy to be such a common measure. Indeed, sustainable systems are much more energy efficient than modern high-input systems. Low-input rainfed rice in Bangladesh and China can produce 1.5-2.6 kg of cereal per megajoule of energy consumed. This is some 15-25 times more efficient than irrigated rice produced in Japan and the United States of America. On average, sustainable systems produce 1.4 kg of cereal per megajoule compared with 0.26 kg/MJ in conventional systems. Modern agricultural systems depend heavily on external inputs, largely derived from fossil fuels. In most industrialized countries, energy is cheaper than labour. Hence, it seems rational to overuse natural resources and underuse labour. The result has been adverse, long-term effects on the environment (Pretty, 1999). Although labour is cheaper than energy in many developing countries, agriculture often has negative effects on the environment. In relation to their policy implications, the environmental externalities of agriculture operate at different geographic scales, e.g. carbon sequestration (a positive externality) on a world scale, but salinization of a watershed on a local scale (a negative externality).

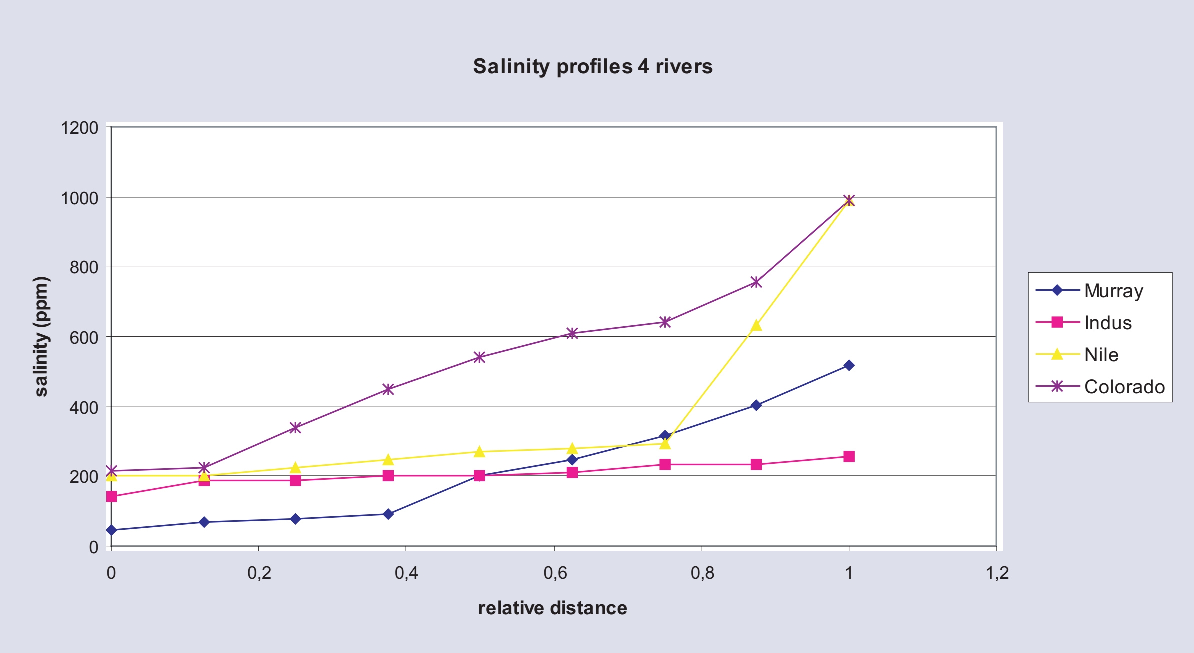
Applying concepts such as the 'polluter pays' principle, cost recovery and cost sharing may prove unrealistic, impractical or politically disastrous to governments in countries where millions of people are poor and small-scale farmers are trying to make a living on marginal lands. A common concern in developing countries is how agricultural production in marginal areas can fulfil its primary function without depleting the natural resource base. For these reasons, developing appropriate technologies, assigning individual or common property rights, and the promotion of alternative employment outside the agricultural sector will be key strategies.

THE SALINITY AND DRAINAGE QUESTION

Much of the environmental impact of irrigated agriculture is linked to the management of water and salt balances of irrigated lands. This includes both minimizing the amount of water required to remove salt from the root-zone, and minimizing the land area required to store the salt temporarily or permanently. Good management has proved difficult. Although human-induced salinity problems can develop swiftly, solutions can be time consuming and expensive. Various improvements in irrigation and agronomic practices can be introduced depending on the type of salinity and on the cause of the accumulation of salts to harmful levels in the rootzone. The fact that saline waters have been used successfully to grow crops shows that under some conditions, e.g. in Mediterranean climates with winter rains, saline water can be used for irrigation. Experience in other locations, where negative long-term effects from irrigating with saline or sodium-rich waters have been observed, indicates that more permanent interventions in the water and salt balance are generally required.

All arid-zone rivers have natural salt profiles, attributable to mobilization of salts in the catchment area and saline seeps. An additional cause of river salinity is irrigation-induced transport of fossil salts owing to pumping from the groundwater into drains that discharge into the river. **Figure 3** shows the salinity profiles for four rivers. It illustrates the various degrees to which salts are returned to the river or remain in the land and the

Figure 3 Salinity profiles in four major rivers *Source: Smedema, 2000*



groundwater (Smedema, 2000). Increases in the salinity of rivers and streams in many dry parts of the world pose an ecological hazard that has been largely overlooked. The ecological impact of increased salinity in inland waters warrants greater attention in view of the vulnerability of aquatic ecosystems to increased salt levels.

Most of the drainage water from agricultural land in Punjab, Pakistan, is reused, either from surface drains or pumped up from shallow groundwater. In fact, in some systems in Punjab, one-half to two-thirds of the irrigation water is pumped from the groundwater. Therefore, the leached salts are returned to the land rather than disposed of in the river system or in evaporation ponds. The average salt influx for the Indus River water is estimated to be about twice the amount that flows out to sea. Hence, half of the annual salt influx remains in the land and the groundwater. Most of the accumulation takes place in Punjab. A more extensive drainage system is needed in order to maintain a sustainable salt balance in the irrigated lands. Worldwide, only 22 percent of irrigated land has a drainage system (less than 1 percent of irrigated land has subsurface drainage). This makes it inevitable that more land will go out of production because of waterlogging and salinity. In general, those people who will lose their land are already very poor farmers.

The drainage situation in Pakistan is in sharp contrast with that in Egypt (**Box 11**). In Egypt, subsurface drains that take the drainage water back to the river underlie a large portion of the irrigated land. The salts do not stay in the Nile Basin but are discharged into the Mediterranean Sea. During part of the year, the salt content in the lower Indus River is much lower than in the lower Nile River (in the Nile Delta) and more salt disposal into the Indus River could be accepted. However, during critically low-flow periods, such disposals would not be possible. The only option during such

Box 11 Egypt's drainage system *Source: Ali* et al.*, 2001*

In the past, serious salt problems had not been associated with the large irrigation area of Egypt. It was only after the widespread introduction of perennial irrigation that measures to counteract salinization were needed. Factors that have contributed to the worsening of the problem include the expansion of irrigated agriculture into sandy or light-textured soils with inherently higher percolation and seepage rates. Much of this newly irrigated land lies on the Nile Valley fringes of higher elevation, which contributes to salt movement toward the low lying lands. Perennial irrigation has led to more seepage throughout the irrigated areas, exacerbated by an increase in rice and sugar-cane production requiring higher water-application rates. Drainage reuse is widespread and not easily identified. The simple arithmetic of farm-level water productivity of about 40 percent and a basin-level water productivity of 90 percent suggests that water is applied at least twice on average. The remainder, which is too saline for reuse, goes to the Mediterranean Sea or to lakes used as evaporation ponds (close to the sea).

Since 1970, Egypt has provided an area of almost 2 million ha with subsurface drainage and associated infrastructure, such as open drains and pumping stations, to transport and reuse the drainage water. An additional 50 000 ha is drained each year. Egypt's drainage programme is one of the largest water management interventions in the world. The total investment amounts to about US$1 000 million, and since 1985 part of the investment has been used for the rehabilitation of old drainage systems. Since the installation of the drainage systems, yields have increased and there has been a substantial improvement in the salinity-affected lands.

Plate 13 Dredging irrigation canal (Egypt)

periods would be to store the drainage water temporarily for release during high-flood periods. Extending the Left Bank Outfall Drain, now operational in Sindh, into Punjab could provide a more permanent, but quite expensive, solution than the present inadequate number of evaporation ponds.

WASTEWATER REUSE

The reuse of municipal and industrial wastewater in irrigated agriculture is widespread. Some of the wastewater is treated before it is reused. However, much of it is not, and this causes significant environmental and health hazards. In addition, many of the treatment plants in developing countries operate below design capacity, which contributes to the discharge of untreated wastewater into irrigation and drainage canals. Concentrations of heavy metals in canal and drain sediments and in soil samples, as well as faecal coliform bacteria counts in canal and drainage water, often exceed WHO water-quality guidelines. For example, wastewater constitutes 75 percent of the total flow of the Bahr Bagar Drain in the Eastern Delta, Egypt, effectively turning the drain into an open sewer. Soil samples in the Eastern Delta showed cadmium levels of 5 mg/kg, more than twice the natural level. Evidence of uptake of trace elements in crops has also been reported. For example, in the Middle Delta, Egypt, cadmium levels of 1.6 mg/kg (ppm) have been found in rice. Such levels are harmful for human health, and warrant serious attention. Thus, some of the drainage water is unfit for reuse, not because of its high salt content but because of its pollution load. In addition, safe disposal of such polluted wastewater becomes a real problem (Wolff, 2001). Similar cases have been reported for other countries, e.g. Pakistan and Mexico (Chaudhry and Bhutta, 2000).

Box 12 Environmental impact of unplanned groundwater abstraction

Source: Shah et al., *2000*

Unplanned and unmeasured groundwater abstraction can cause considerable damage to fragile ecologies. An example is the Azraq Oasis in Jordan. The Azraq is a wetland of more than 7 500 ha that provided a natural habitat for numerous, unique aquatic and terrestrial species. The oasis was acclaimed internationally as a major station for migratory birds. However, it dried up completely as a result of groundwater mining upstream through pumps for irrigation and the water supply for the city of Amman. Overdraft resulted in the decline of the initially shallow water table from 2.5 to 7 m during the 1980s, drying up the natural springs whose supply to the oasis fell to one-tenth of its flow in the ten years from 1981 to 1991. The whole ecosystem collapsed and the salinity of the groundwater increased from 1 200 to 3 000 ppm. However, through a combination of reverse pumping of water from elsewhere into the centre of the lake, cleaning of springs and rehabilitation, it has been possible to restore the Arzaq wetlands almost to its original state, and the birds (and the tourists) have returned.

The challenge of managing the conjunctive use of groundwater and canal water successfully has been alluded to before. In some areas, over-abstraction of groundwater is evidenced by the rapid dropping of water-table levels. In other areas where the groundwater is too saline for agricultural production, the water table rises as a consequence of over-irrigation and seepage from irrigation canals. Much agricultural land has gone out of production as capillary rise from shallow water tables has ruined soils and poisoned crops. Reversing this process is difficult and expensive (**Box 12**). In India, the extent of the waterlogged areas is estimated at 6 million ha. In 12 major irrigation projects with a design command area of 11 million ha, 2 million ha are reported to be waterlogged and another 1 million ha salinized (Shah *et al.*, 2000).

It is estimated that salinization alone causes 2-3 million ha/year of potentially productive agricultural land to be taken out of production. How much of this land is reclaimed (to various degrees) and then cultivated again is unknown. Pollution of groundwater by salts and residues of agrochemicals is also a common occurrence. Where slightly saline groundwater is used for irrigation, the repeated cycles of water application to the fields, seepage of the excess water and pumping it up again from the top of the aquifer increases the salt load of the groundwater. If the vertical permeability of the aquifer is restricted, only limited mixing of seepage water takes place and the top of the aquifer from which the water is pumped becomes increasingly saline. This process has been documented for several irrigation systems in Punjab, Pakistan, where conjunctive irrigation with canal water and groundwater takes place (Kijne *et al.*, 1988).

The poorest farmers are those most vulnerable to environmental degradation as most of them farm under difficult growing conditions. A few farmers cultivate the best lands; the vast majority of the farmers cultivate the less fertile and marginal lands. Further degradation is likely to affect the quality of the farmers' sources of drinking-water and irrigation water, the quality of their land, possibly the quantity and quality of the fish they catch, and ultimately their health. Lack of data on water and salt balances of irrigated land and lack of knowledge on how much water (and of what minimum quality) should be committed to downstream users frustrate attempts to allocate water more equitably to users in order to improve basin-level water productivity in agriculture. The way forward to ending unsustainable practices and reducing the concentrations of salts and agrochemicals that result directly from the degradation of the soil and water resources is a consolidated and long-term effort to improve land and water management.

Generally, agriculture and rural development have not benefited from systematic environmental analysis and management. One reason for their exclusion in the past was probably the very large number of projects (large and small) that could have been referred for an assessment, which would have overwhelmed the environmental assessment agencies. Environmental impact assessment (EIA) is usually applied to physical project planning (e.g. dams, roads, pipelines and industries), but seldom to farm practices and rural development plans. As a result, inadequate planning and inappropriate land-use practices have persisted. In many areas, soil, land and water resources are used inefficiently or are degraded, while poverty and income disparities grow.

With some 30 years of experience, EIA techniques now usually consider not only biophysical impacts but also socio-economic effects on health, human migration in and out of the project area, training of local workforce, local government capacity building, etc. Government and international policies are still needed to establish appropriate legal frameworks and an institutional base for EIA for agricultural projects. These policies should include transfer of the necessary knowledge to the rural poor, e.g. through agricultural extension services, so that they can participate in the environmental assessment of agricultural water resource management and project planning (FAO, 2002d).

chapter 6 Modernizing irrigation water management

THE SCOPE OF MODERNIZATION

Modernizing water management in irrigation systems can be interpreted in different ways depending on the local circumstances. One type of modernization is the introduction of modern technologies, such as water application and distribution through pipes rather than open channels, and the use of computerized soil-water sensors to trigger water applications. However, it also comprises older capital-intensive techniques, such as canal lining and land levelling. These techniques can only be introduced and used successfully where the farmers can be trained in their use or already possess the necessary skills. However, the technical side is only one aspect of modernization. Equally important are fundamental changes in the institutional arrangements and regulations and improvements in the performance and efficacy of water users and their organizations.

FAO has defined modernization as "a process of technical and managerial upgrading of irrigation schemes combined with institutional reforms, if required, with the objective to improve resource utilization and water delivery service to farms" (Facon and Renault, 1999). In this sense, modernization offers a means of institutional reform with a purpose, not just reform for its own sake. It is systemic and practical without asking that all institutional elements change and it needs to be applied where irrigated agriculture has a clear comparative advantage.

Irrigation institutions need to adopt a service orientation and improve their performance in economic and environmental terms. This entails: adopting new technologies; modernizing infrastructure; applying improved administrative principles and techniques; and promoting the participation of water users. Irrigation-sector institutions need to link their central task of providing irrigation services to agricultural production and to

Plate 14 A farmer preparing irrigation pipe in a field of tomatoes (Brazil)

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integrate their water demands and uses with other users at basin level. An enhanced appreciation of the water cascades and flows across landscapes and the circulation of groundwater within aquifers will lead to informed decisions on the use and reuse of agricultural water.

Because modernization is usually perceived as an engineering project, its planning typically focuses on engineering and macroeconomic issues with only broad assumptions about how the delivery system and the on-farm irrigation systems are to be managed. Where the modernized system turns out to be incompatible with existing management practices or where unanticipated extensive changes in management practices are needed to take full advantage of the potential of the modernized system, then the modernization project is likely to fail.

In addition, failure is likely if the public irrigation organization continues as before without the involvement and participation of the water users in the system's operation and management. Only through their involvement from the beginning of a modernization project can farmers develop a sense of ownership and be likely to care for the system. This sense of ownership should prevent several of the problems that often arise after a short time: field channels being demolished; gates being stolen or damaged; field drainage systems becoming blocked; open drains filling with sediments and weeds; and graded land becoming spoiled by bad tillage. **Box 13** presents some of the lessons learned from irrigation modernization projects.

Box 13 Irrigation modernization in Argentina, Mexico and Peru

Source: FAO, 2001d

A set of conditions for the success of modernization projects can be drawn from an analysis of recent irrigation modernization in Argentina, Mexico and Peru:

- Modernization is more likely to succeed if the ideas come from the farmers.
- Pressure irrigation is 'in' and gravity irrigation is 'out'; future irrigation development should be for pressurized irrigation.
- Much attention needs to be given to efficient water distribution; otherwise, high water losses, water theft, and unscheduled irrigation will continue.
- Payment of water service fees remains a problem unless farmers are taught and accept that water cannot be free.
- Providing farmers with appropriate technical assistance requires considerable attention. Despite the training provided, there are still large gaps in knowledge about farming practices, water requirements and irrigation scheduling.
- Each system requires tailor-made solutions: modernization always includes improving the physical infrastructure, but how this is done and all other needs are site-specific.

The case studies indicate that, because of severe competition for water, the water delivery system in irrigation has to become more efficient soon or the system will cease to exist. In the long run, reliance on government contributions and subsidies is no longer an option, although the transition phase to modernized management may still require substantial public investment. The three cases of modernization were successful in the sense that farmers became aware that business as usual is no longer possible. However, as technology is changing so rapidly, it may be necessary to modernize more or less continuously in order to adjust to the changing circumstances.

An important aspect of modernization is the effect of intended plot sizes on the feasibility of the project. For example, in Navarra, Mexico, the average plot size is about 5 000 m^2 while the average area owned by one farmer is 1.3 ha. It is likely that in the near future these farms will not be economically viable for two reasons: (i) the small plot size; and (ii) the poor condition of the irrigation systems (FAO, 2002d). The modernization of many irrigation systems should encompass restructuring land tenure in order to ensure plot sizes that can be farmed profitably. In this system in Mexico, such a plot size is thought to be about 5 ha. Increasing plots sizes will also allow a reduction in the investments needed to modernize the irrigation systems. In addition, farms that perform well will have the capacity to generate jobs both directly and indirectly.

Nonetheless, site-specific considerations can lead to different conclusions. In Mali, the Office du Niger, which is dedicated to rice production, allocates individual plots of at least 5 ha. This allocation of large plots to full-time, maximum-profit farmers is seen to be inconsistent with the reality of people generally pursuing diversified livelihoods, especially when trying to escape from poverty. Moreover, small plots are often used more intensively. For example, in Zimbabwe in the early 1990s, the government changed its policy of giving farmers irrigated plots of 0.1 ha so they could supplement their income from rainfed agriculture, to giving each farmer 3-5 ha of irrigated land. The expectation was that the larger plot sizes would induce farmers to devote themselves full-time to irrigation. The policy also favoured giving the irrigated land to men, with the idea that they would be more likely to devote their energies to irrigated farming. However, productivity per unit of land and productivity per unit of water were later found to be higher on the smallholding system, and women farmers were significantly more likely than men to be oriented towards irrigation as their main source of food and income (FAO, 2002d).

Large-scale irrigation development and modernization projects tend to concentrate on the production of staple foods while ignoring the fisheries. A main issue with loss of fishery habitat, or specifically with the reclamation of wetlands for agriculture, is that once the wetland is converted to agricultural land, people can have title to it. Legal title to natural wetlands is not possible although traditional communal rights can be recognized. Fisheries are often taken for granted. Many people fail to see the benefits of wetlands and fisheries, whereas they realize that quantifiable benefits, such as agricultural production and hydropower, will flow from new development works. Examples of undervaluing inland fisheries can be found in Cambodia, Sri Lanka and Bangladesh (FAO, 2002d). For a balanced diet, rice needs to be supplemented with animal protein, and inland fisheries provide one of the cheapest and most readily available sources of such protein. However, development decisions that affect the management and use of inland waters are often made without accurate and complete knowledge of the contribution that inland fisheries make to rural livelihoods. One lesson from many such examples of modernization projects is that a project is not necessarily good or bad, but rather that full knowledge of the local conditions and cultures is essential for its successful implementation. The goal in modernizing irrigation institutions is not only to improve water management in agriculture but also to promote integrated water resource management (IWRM), which takes into account the social, economic and environmental sustainability of all management of the water resources.

THE ROLE OF LOW-COST TECHNOLOGIES IN MODERNIZATION

The introduction of low-cost technologies, which could be part of the modernization of small-scale irrigation projects, provides another example of the site-specificity of success. Inexpensive treadle pumps have been successful in some South Asian countries in extracting irrigation water from shallow aquifers. These pumps have allowed poor farmers to make good use of the available labour in their households and so increase crop production and farm income. The farmer has full control over the timing and amount of this pumped water, which given the effort involved is used sparingly. For example, the area under irrigation by one treadle pump in West Bengal, India, varies between 0.033 and 0.13 ha. Treadle pumps have also been introduced in Africa, including the urban and peri-urban areas of Ndjamena, Chad. Here, the vegetable growers rejected the pumps in favour of mechanical pumps because they could afford the cost of fuel and spare parts. However, in the more remote areas of Sarh, Chad, farmers were content with the treadle pumps and requested more of them (FAO, 2002d). Treadle pumps are intrinsically pro-poor, as

Plate 15 Tachai: farmer using hand-operated pump to draw up water from canal (China)

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richer farmers would not be able to persuade household members to use them. A limitation of treadle pumps is that their use requires spare labour, which may not exist. Women are usually already overburdened. Healthy children could do the pumping, provided it does not interfere with school attendance. Therefore, it is important to assess labour availability before introducing treadle pumps (FAO, 2002d).

Positive experience has been reported with the introduction of bucket drip-irrigation kits. These kits are suitable for the irrigation of small plots of vegetables and fruit trees in peri-urban areas (close to markets). In Kenya, the return on an investment of about US$15 for one bucket drip-irrigation kit was some US$20 per month. Farmers in Kenya have bought over 10 000 kits, although some of these farmers could not described as very poor (FAO, 2002d).

chapter 7 Conclusions and actions

FAO predicts that additional water development will be needed in order to accommodate the needs of another 2 000 million people by 2030. If gains in water productivity can be maintained, the pressure on resources can be reduced and the scope for transfers to other users expanded. The increase in agricultural water productivity has been the result of strategic investment in water development but also in research and development and in agricultural extension. The current investment trends in these components show a sharp decline. The future of agricultural water management will depend on maintaining levels of investment in key areas of the production chain, not jsut in water control infrastructure alone. In this respect, it is the quality of the investment, rather than the quantity, that will be critical.

Given that demands for food are non-negotiable, the only scope for improving overall water management will hinge on the continued improvement of water productivity in existing agricultural systems (rainfed and irrigated). Therefore, investment should comprise a strategic package combining: research investment to develop more productive biological materials; improved agricultural practices; capacity building for farmers and users; promotion of agricultural trade to improve global productivity; and new resource development where necessary.

Water requirements for an anticipated stabilized population of about 8 000 million are not easy to predict. The precise amounts of water that must be available at specific locations for sustainable crop production have their own spatial and temporal variability. The problem is compounded by uncertainty with respect to the amount of water required to maintain ecological integrity and for the recharge of overexploited aquifers. Finally, the impacts of climate change on raw water availability and the demands of agriculture remain conjectural. Considering all these unknowns, providing enough water for the global production of adequate food supplies represents an enormous challenge, particularly in regions and countries where water is already scarce. This uncertainty about future water availability and the demands to ensure food security frustrates decision-making on investments for agricultural water management. The questions that need to be answered are:

–> How much additional storage capacity in dams and reservoirs is required?

–> How can nations and regions ensure the sustainable use of pumped groundwater that is critical to agricultural production?

–> How can additional sources of water, such as municipal and industrial wastewater, be best used in irrigated agriculture without adverse effects on human and ecological health?

This paper has discussed the link between irrigated agriculture and poverty alleviation and rural development. Indirect effects of irrigation on rural development have been notable, especially through the creation of off-farm employment opportunities for poor people. However, other investments, e.g. in roads and markets, could often be of even greater direct value to rural development. Thus, for investment to have the greatest possible impact on poverty alleviation, governments and funding agencies are faced with difficult choices between direct investment in agricultural water infrastructure or 'leading' investment in market creation and access.

System-level improvements in irrigation and drainage infrastructure and in the institutional and policy arrangements for managing these systems will enhance water productivity and hence food security. However, the greatest benefits are expected from integrated crop and resource management. These will accrue when the three components of plant breeding, agronomic improvements, and changes in the operation and management of irrigation facilities work together so that the potential benefits of new crops and varieties are fully realized. There are few successful examples of this three-way collaboration. Its realization amounts to reinventing agricultural water management. Equally, improved agronomic practices in farmers' fields, such as zero tillage and raised beds, will also lead to greater water productivity in agriculture. However, the adoption and adaptation of these techniques has been slow.

IWRM has been heralded as a framework for planning, organizing and controlling water systems in order to balance the views and goals of all relevant stakeholders (Grigg, 1999). This definition includes two dimensions of interdependence: social (balancing views and goals of stakeholders) and ecological (managing multiuser water systems). In the past, water had two main purposes: for domestic uses and to produce food for growing populations. Today with the competition for water, such simple objectives are no longer acceptable. Advocates of IWRM believe that a move to a more sustainable irrigation sector depends on well-functioning WUAs. However, it has proved difficult to start WUAs. Before WUAs can be set up successfully, it is necessary at a minimum to assess the water resources, assign water rights to legitimate users, and define institutions for administering the water rights. Conflicts of interests between the various stakeholders make it difficult and expensive to satisfy these three prerequisites. Moreover, there is growing evidence that irrigation management transfer risks aggravating rural poverty unless a pro-poor mode for this process is designed and implemented (van Koppen *et al.*, 2002).

A critical issue in terms of the resource base is the overabstraction of surface and groundwater resources, which in many locations appears to be unsustainable. In discussing sustainable management of groundwater resources, some people suggest that exploitation of the groundwater resource beyond its recharge level can be justified if it initiates sustainable development by using the income from pumped groundwater for useful purposes. Nevertheless, by the advancing water-saving technology, promoting land management and other long-term benefits, a contribution to sustainability can be claimed (Kinzelbach and Kunstmann, 1998, Barker *et al.*, 2003). The strategic choice of how much environmental degradation can be justified for the sake of increasing food security or reducing poverty is a difficult one. The trade-off is neither simple nor direct since alleviating poverty can in fact prevent environmental degradation.

These conclusions indicate that, unless national governments and funding agencies make several strategic choices regarding agricultural water management, the agriculture sector will not be in a position to maintain current water allocations for the strategically important food production produced by irrigation.

For national governments, the choices imply:

1. Accepting the fact that there is no single solution for maintaining food security when water is scarce. All sources of water (rainwater, canal water, groundwater and wastewater) are important. They can all be developed under the right set of conditions, and additional storage capacity and recharge of groundwater resources form part of the long-term solution.

2. Finding the best options for specific conditions. Good and poor-quality land can be used for the production of food crops and other commodities, and the best combination of land, crop and water is site-specific but not ignore the inherent productivity of natural ecosystems.

3. Realizing that the link between irrigated agriculture and rural development is not always straightforward, trural development may be better served by investments in sectors other than irrigation.

4. Adopting natural resource based policies and institutions that encourage the integration of crop and resource management in order to identify the best location-specific options.

5. Facilitating and supporting actively the development of improved varieties as part of the solution for future food security.

6. Supporting actively the application of seasonal climate predictions in order

to create the best combination of crop and resource management for the anticipated climate conditions.

7. Investing in irrigation modernization as an ongoing process, while recognizing each system's specific comparative advantages. The aim of modernization should be to make the water delivery system and its management flexible enough to take full advantage of new technologies and crop varieties.

For donor agencies, the choices for strategic investments in agriculture imply:

1. Accepting agriculture as the sector where the potential for generating water savings through productivity gains is greatest.

2. Linking global goals and global finance with local initiatives and local needs. Funding should be tailored to the specific physical and socio economic settings

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Unlocking the water potential of agriculture

All statistical evidence confirms that agriculture is the key sector for water management, now and in the next decades. Nevertheless, the rural water development sector fails at present to get priority compared to other competing sectors in international fora. Strong and new arguments are needed to bring rural water back "on line".

The prospects for the future are clear. Agriculture will have to respond to changing patterns of demand for food and combat food insecurity and poverty amongst marginalized communities. In so doing, agriculture will have to compete for scarce water with other users and reduce pressure on the water environment. Agriculture policies and investments will therefore need to become much more strategic. They will have to unlock the potential of agricultural water management practices to raise productivity, spread equitable access to water, and conserve the natural productivity of the water resource base.