Chapter 9
Economics of spate irrigation

SUMMARY

Returns to agriculture in terms of spate irrigation are often low and the scope for deriving significant additional economic benefits from investment is constrained because of:

- variations in cropped area and crop production from year-to-year and season-to-season;
- inherent risk of total crop failure in certain years with no or damaging floods;
- domination of staple crops with limited market value; and
- limited potential gain in water productivity resulting from the relatively high diversion and conveyance efficiency of existing spate systems.

Evidence shows there is no scale economy for spate irrigation. Unit costs tend to increase as systems become larger because of the technical complexity related to such systems, and the much larger flows that need to be taken into account in the design of civil engineering works. Smaller spate systems are less complicated and can avoid expensive and complex infrastructure such as cross-river siphons, sedimentation ponds and lengthy flood channels. In this respect the trend in spate irrigation is opposite to that in perennial irrigation investments. Investment in smaller spate systems may have a better return than those in large spate systems. The picture may, however, change if spate irrigation is combined with shallow groundwater use or adequate local rainfall, or when care is taken in soil moisture management.

In designing spate irrigation improvement projects, the trade-offs between investment costs, maintenance costs and the level of service deserve more attention than in the past. In particular, the very nature of arid zone hydrology requires a different approach towards risk management than for perennial irrigation infrastructure. Provision for rebuilding parts of the system, after major floods, are often a more cost-effective option than designing permanent structures. Similarly, designing simple un-gated headworks may, in many cases, be more cost-effective than sophisticated structures, and present less operational constraints, while ensuring satisfactory distribution of water to the fields.

Economic analysis of development options should include investigation of links between initial costs and subsequent maintenance costs, using realistic valuations of farmers' input. A low-cost approach may have significant sustainability and 'ownership' advantages:

- a simple technology that can be easily maintained;
- less dependent on heavy machinery and imported materials and supplies;
- most of the construction works can be carried out by farmers themselves;
- repairs are less costly and can be executed faster as only locally available materials and/or skills are required; and
- the impact of failure is partial as diversion structures have smaller command areas.

The benefits of spate irrigation cannot be assessed only on a foreseen increase in crop production. Investments in spate irrigation often have significant social and environmental benefits. The assessment must take into account the recognition that farmers in spate areas often have no viable alternative means of support. The impact of sustaining and supporting these systems, thus, differs from investments where the main target group has access to alternative livelihood opportunities. Social and environmental benefits of spate irrigation should be included in an economic analysis, as a minimum, scores should be allotted in accordance with the importance. A list of such benefits is provided in this chapter.

INTRODUCTION

Returns on investment in spate irrigation is generally low and often does not justify large capital outlays. This, however, has not prevented large investments being made in spate-improvement projects in the past, often with doubtful results. Yet, cost-effective improvements are possible in spate-irrigation systems that can contribute substantially to poverty alleviation, improvement of rural livelihoods and local food security. Some investments – examples are given in this chapter – can be returned within a year. Moreover, spate irrigation can significantly contribute to wider basin resource management and improved sustainability of fragile arid environments. These externalities should be taken into account when assessing the benefits of spate irrigation development.

This chapter discusses the economics of spate irrigation, focusing on the costs of improvement options. Benefits are assessed looking at different planning horizons and the broader livelihood and environmental impacts.

ECONOMIC ANALYSIS OF SPATE SCHEMES

Any investment in improving or modernizing traditional spate irrigation systems can only be economically feasible if the net economic benefits are significantly higher than the economic returns of the traditional spate-irrigated agriculture. The scope for deriving significant additional economic benefits from investments in spate irrigation is limited by the following factors:

- the cropped area and crop production vary considerably over the years because of variations in the size and frequency of floods;
- there is an inherent risk of total crop failure in years with no floods or very large floods that wash away the diversion structures before any land can be irrigated;
- cropping patterns that, in most areas, are dominated by the cultivation of traditional crops having limited market value and are grown mainly for home consumption; and
- the diversion and conveyance efficiency of most spate-irrigation systems, which is already relatively high as most surface water is used for irrigation, finds its way to groundwater recharge, or is used for the flooding of forests or grazing areas.

In many cases, substantial economic benefits may, however, come from higher water productivity through the conjunctive use of groundwater and spate water, improved soil moisture management, better flow distribution and improvements in agronomy (see Box 9.1)

As the scope of potential economic benefits from investments in spate irrigation is relatively limited, and to ensure that the improvement of spate irrigation systems make sense in economic terms, development costs must be proportional to expected benefits. A robust, low-cost approach has the following significant advantages:

- simple technology is used that is easily adopted by local farmer-engineers, ensuring that both construction and maintenance can be undertaken at the local level, using locally available materials;
- most of the construction works can be carried out by the farmers themselves;
- repairs are less costly, and can be executed faster, as only locally available materials and/or skills are required; and
- the impact of failure is partial as low-cost diversion structures have smaller command areas than larger, permanent diversion structures.

BOX 9.1
The ingenuity of the Mochiwal division structure in Pakistan

Mochiwal Division on the Darabam Zam in Dera Ismael Khan (Pakistan) is probably one of the most cost-effective spate irrigation investments. The Mochiwal division structure consists of three-gated divisions, operated with hoisting gear. The function of the structure is to distribute the flow between two spate irrigation channels – the North and the West Channel. The cost of the structure including the short guide bund sections was US$2 000.

Prior to the Mochiwal Structure, the flow of the Darabam could not be controlled. It disappeared in its entirety to the low lying North Channel areas, every time causing considerable damage to this flood channel (see picture). The water could not be controlled in the North Channel as the spate flow washed away all earthen diversion structures in its path. At the same time the West Canal was left high and dry in most years.

The Mochiwal Structure now controls the inflow into the North Channel and keeps the flood to a manageable quantity. At the same time, it diverts the water from Darabam to the West Canal command area, where there is substantial land. An investment of US$2 000 restored and safeguarded farming on 3 500 ha.

In fact, some of the most expensive investments, e.g. Wadi Siham diversion structures, have been amongst the least successful. While low-cost options are attractive when considering economics and sustainability, it is also important to consider the level of service that can be provided. There are very few examples of farmers wishing to dispense with even poorly designed permanent diversion structures (although they may often wish to modify them) and return to their labour-intensive traditional diversion arrangements. Finally, the feasibility of investment in spate irrigation depends upon the probability of receiving water. Areas with a more reliable supply of spate water justify higher levels of investment than areas with a less reliable supply of spate water. In areas where the flood probability is once every ten years, it is hard to justify extensive investment.

COST OF SPATE IRRIGATION DEVELOPMENT

As discussed elsewhere in this report, several types of programmes have supported the improvement or modernization of spate irrigation. These programmes have had varying degrees of success. It is obvious that investment in civil engineering to provide permanent gated headworks and new canals in large systems has attracted most visibility. Nevertheless, it has also drawn criticism because of the high development costs, and the often disappointing and sometimes even negative impacts.

Table 9.1 gives an overview of investment costs per hectare for different types of interventions in different countries. It is evident that unit costs very much depend on the nature and size of the system and the type of intervention. In general, very high costs were incurred in systems that involved the construction of permanent headworks and new canals on large systems.

Contrary to what may be expected, economies of scale do not apply in spate irrigation. One reason is that development or improvement costs are very much concentrated in headworks, while the command area may vary substantially in relation to availability of land and water. In addition, unit costs tend to increase as systems become larger because of the technical complexity of larger systems, and the much larger flows that have to be taken into account when designing civil engineering works.

In large systems, a diversion structure has to span a wide wadi, and stand up to very large design floods. Permanent structures cannot be allowed to fail in large floods, as in traditional systems. Often, because of the costs involved, a single headwork is constructed supplying water to canals that were formally supplied from their own individual intakes. This requires the development of lengthy new supply canals and extensive bank protection. When there are irrigated areas on both sides of a wadi, a siphon or conduit under the wadi bed is needed to pass irrigation flows to the other bank, which adds to the costs (double-sided intakes are generally not used because of the difficulty of managing water distribution between both banks).

The cost per hectare for a system with civil headworks on a large project (1 500 ha and above) are between US$1 350–2 000/ha (with some exceptional peaks above this amount). While the cost for permanent headworks on small systems is considerably less: US$180–450/ha. The cost for systems with non–permanent headworks, essentially soil bunds, is far less again (mainly below US$125/ha). These soil bunds, though not permanent, are not necessarily rebuilt every year. The Rehanzai Bund in Pakistan, for instance, has been in operation for more than 20 years.

In general, permanent headworks on small systems and investments in soil bunds provide high returns and defeat the notion that investment in spate irrigation is unrewarding. Such programmes may achieve costs of water storage (in the soil profile) that are highly favourable compared to investments in other water control structures in arid areas, especially dams. The same argument extends to supporting improved soil moisture conservation, command area programmes (such as gully plugging) and investing in conjunctive use of groundwater and spate flows. In many cases, investment in such activities, as well as complementary programmes in improved agronomic practises, show the highest dividend.

This is exemplified by the study of the economic rate of return (ERR) of spate irrigation projects. An FAO study on investment costs in irrigation *(Salman et al, unpublished)* included information on the economic rate of return, looking at the different types of irrigation: spate, localized, sprinkler and surface irrigation. The comparison between the four categories is given in Table 9.2 and shows that spate irrigation systems in the study managed an acceptable rate of return.

The analysis shows that the economic rate of return (ERR) for surveyed spate irrigation projects correlates negatively with the size of project and the unit cost, proposing that the ERR tends to be higher for smaller projects (see Figure 9.1). As smaller spate irrigation systems are less complicated, expensive and complex infrastructure can be left aside, they do not need cross-river siphons, sedimentation ponds and lengthy flood channels, which means they may tend to be better off economically than are larger systems.

TABLE 9.1
Development costs of different types of spate irrigation projects

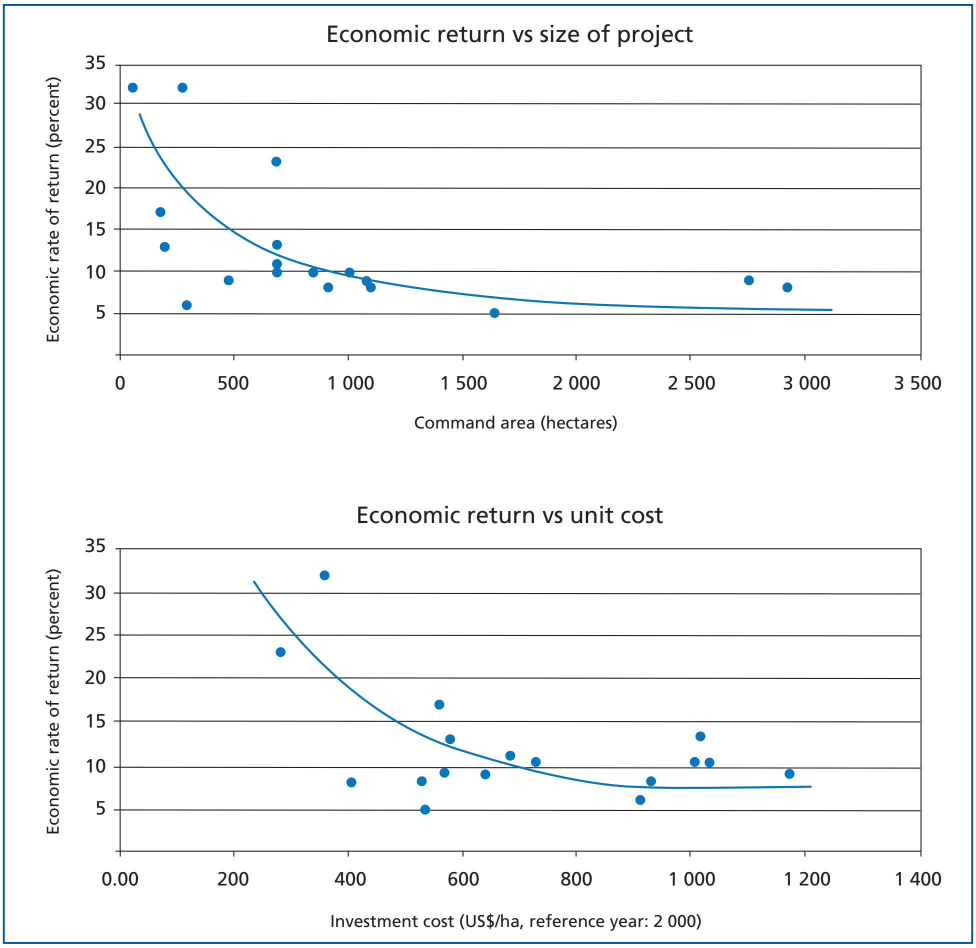
Intervention	Unit Cost (US$/ha)	Description
Non permanent headworks		
Rehanzai Bund, Pakistan	5	Large soil bund and embankments with gabion core, diversion channels – irrigating 12 000 ha (1984)
Gathelay, Eritrea	51	Soil bunds, gabion structures (2002)
Karkhi Bund, Kharan, Pakistan	70	Bulldozer built soil bund–irrigating 20 ha, but larger potential (1993)
Wadi Labka, Eritrea	110	Gabion reinforced guide bunds to flood channels
Miscellenous systems in Omomyya	170–220	Soil bund, gabion structures
Grasha, Eritrea	123	Soil bund and diversion channel
Garen Bygone, Iran	160	Flood water spreading
Permanent headworks, small systems		
Mochiwal, Pakistan	1	Flow splitting structure at critical point
Alebu, Eritrea	181	Diversion weir and guide bund
Mogole, Eritrea	341	Diversion weir and guide bund
Bultubyay, Eritrea	444	Diversion weir, guide bund, and flood channel
Rehabilitation		
Dameers Hadramawt, Yemen	90	Small systems
Dameers Hadramawt, Yemen	151	Small systems
Command area works (Irrigation Improvement Project), Yemen	150–300	
Sidi Bouzi, Tunisia	252	Small system
Oum Aghanim, Morocco	620	Diversion weir, canal, distribution structures
Tambardoute, Morocco	699	Diversion weir, canal, distribution structures
Touizgui, Morocco	628	Diversion weir, canal, distribution structures
Afra, Morocco	895	Diversion weir, protection bund, distribution structures
Permanent headwork, large systems		
Koloba, Ethiopia	250–350	Diversion weir, breaching bund, siphon
Nal Dat, Pakistan	646	Not built
Marufzai, Pakistan	1 346	
Wadi Laba, Eritrea	1 420	Diversion weir, breaching bund, siphon (2000)
Barag, Pakistan	1 478	
Sidi Bouzi, Tunisia	1 480–2 500	
Mai Ule, Eritrea	2 420	Diversion weir, breaching bund and diversion channel (2000)
Wadi Labka, Eritrea	3 517	Diversion weir, breaching bund, embankments (not built)
Wadi Siham, Yemen	11 000	Diversion structure, sedimentation pond, flood channel – later replaced by system of flood protection and re-enforced independent intakes

TABLE 9.2
Economic rate of return comparison between different irrigation technologies

Type of irrigation	Average size of projects	Average unit cost	Average rate of return (%)
Spate	6 636	919	12.9
Localized	26 395	1 446	20.0
Sprinkler	21 351	3 196	21.5
Surface	39 490	3 519	20.5

Source: Salman, et al. (unpublished)

FIGURE 9.1
Economic rate of return for spate irrigation projects against project size and unit cost



BALANCING INVESTMENT COSTS, MAINTENANCE COSTS AND THE LEVEL OF SERVICE

There is an element of 'management of expectations' in new infrastructure-oriented schemes. In traditional systems, a degree of unpredictability and a very high maintenance burden is expected. In externally funded infrastructure-oriented projects the standards for water diversion efficiency, and keeping maintenance costs to a minimum, are often given greater consideration; while intermediate options may be more cost-effective. Investment costs must, therefore, be linked to the level of service provided by the different engineering approaches.

Simple soil bunds or spur type diversions, in spite of the cost-effectiveness of their construction with a bulldozer, require frequent repair in the critical sections, often every 1 or 2 years and, in extreme cases, may need to be replaced more than once every year. These systems require more effort from farmers in their operation and maintenance, as uncontrolled flows are admitted to canals work then needs to be done on reconstructing canal diversions, repairing scour damage and, in some cases, removing sediment deposits.

In the right circumstances, a simple permanent intake, provided with effective sediment control facilities, may provide a much higher level of service, and dramatically reduce operating and maintenance requirements over an engineering life of 20 or 30 years. Box 9.2 illustrates this point and gives an example of a high cost concept being substituted by a more cost-effective solution, where the difference in level of service was balanced against overall cost.

BOX 9.2

Gabion guide bunds rather than permanent diversion structures in Wadi Labka, Eritrea

In Eritrea, 1 200 m long gabion-reinforced guide bunds were constructed by the Ministry of Agriculture in Wadi Labka at a cost of US$430 000. In the original project proposal, permanent headworks were proposed for Wadi Labka and a diversion structure was foreseen in the gorge of the ephemeral stream. Wadi Labka is extremely wide and the technical and financial feasibility of this option could never be justified. Instead, a series of gabion-reinforced guide bunds were constructed, combining manual labour and bulldozer work. The gabions served to divide the flood and reduce the likelihood of early washouts in the head section of the flood channels on either side of the Wadi Labka stream. The cost of the gabion river engineering options (US$110/ha) compares favourably with the earlier proposed civil engineering option of US$3 500/ha.

The trade-off between initial investment costs and subsequent operating and maintenance costs in spate systems deserves more attention than has been given to date. Data on the operation and maintenance budgets for four agency-managed schemes with permanent headworks and canal systems in the Tihama of Yemen are shown in Table 9.3. These indicate an average ‘optimal’ O&M cost of around US$33/ha in 1998.

The O&M costs of the Wadi Laba and Mai Ule systems in Eritrea are comparable. These costs are estimated at US$40/ha including the cost of replacing the frequently failing breaching bund. The cost for maintenance in the Gash system in Sudan was estimated at US$14/ha (mainly for de-silting), which is also comparable. Recent data from four spate systems in Morocco put the O&M cost higher at US$54–88/ha. In Yemen and the Sudan, the required budget was far more than the actual budget received, which was mostly spent on maintaining a large permanent agency staff, offices, vehicles and other support services. Very little was spent on actual scheme maintenance. In contrast, in Wadi Laba and Mai Ule, the funds were collected by the Sheeb Farmers’ Association and spent only on system maintenance, thanks to the high productivity of the Sheeb systems which made this possible.

TABLE 9.3
Actual and optimal O&M in four agency-managed systems, Yemen

Intervention	Wadi Zabid	Wadi Rima	Wadi Tuban	Wadi Bana
Area covered (ha)	17 000	8 000	6 606	12 400
Actual situation				
Staff employed	97		486	395
Staff costs (US$)	37 704	25 111	474 074	218 519
O&M budget requested (US$)	76 296	23 704	328 889	222 963
O&M budget received (US$)	14 815	14 074	13 333	26 667
Optimal situation				
Staff number	95	59	84	116
Salary costs (US$)	67 407	45 185	55 556	81 481
Operational budgets (US$)	54 815	32 593	33 333	76 296
Maintenance budgets (US$)	13 333	11 111	11 111	17 037
Depreciation (machinery/vehicles) (US$)	242 222	147 407	145 185	351 852
Total (including 15% miscellaneous) (US$)	434 815	271 852	281 481	606 667
O&M cost (US$/ha)	29	34	35	32
Average cost (US$/ha)	32.8			

Adapted from: Al-Eryani, M. Mohamed Al-Hebshi and Anwar Girgirah (1998)

At the other extreme, the costs of O&M for traditional systems are mostly farmers' direct labour, and their investment in draught animals. These costs vary enormously from scheme to scheme and from year to year, and are not known with any precision. It is reported that in most of the traditional spate irrigation schemes in Eritrea, about 80 percent of the farmers' effort is spent on repair and reconstruction work of diversion structures, field embankments and canals *(Haile, 1999)*. Some estimates of initial and subsequent maintenance costs for a range of types of traditional spate diversion spurs in Eritrea are given in Table 9.4.

TABLE 9.4
Comparison of initial and maintenance costs for traditional diversion spurs in Eritrea

Type of diversion spur	Initial cost (US$)	Estimated damage as percent of initial cost during normal spate season	Number of repetitions of construction during normal spate season	Maintenance cost (US$)
Stone	88	50	1	44.5
Soil	31	100	2–4	63.5–126
Brush wood	40	60	2–4	48.6–97.2
Mixed	60	40	2–4	48–96
Gabion	325	20	–	65

Source: Haile (1999), and Haile and van Steenbergen (2006)

Excluding the gabion option, maintenance costs for traditional diversion spurs average around 1.8 times their initial cost. This figure can be compared with a range of options for other engineering interventions (see Table 9.5). While these approximate figures tell almost nothing about the level of service delivered by the various options, or their long-term sustainability, the trade-off between initial investment cost and the subsequent maintenance burden is very clear.

TABLE 9.5
Relation between initial investment cost and maintenance costs – comparison between traditional and other engineering interventions for spate diversion in Eritrea

Type of engineering	Annual cost of maintenance/initial cost)
Traditional diversion spur, excluding the gabion option (Average from Table 9.4)	1.8
Soil bund (bulldozer)[1]	0.33
Gabion diversion (Table 9.3)	0.2
Permanent headworks and new canals in large agency-managed schemes[2]	0.025

1. Assuming that the bund needs to be reconstructed every 3 years.
2. For an initial development cost of US$1 400/ha and 'optimum' maintenance cost of US$35/ha

For farmer-managed schemes that do not carry the costs imposed by full-time agency management, comparisons of initial investment costs, with best estimates of the lifetime O&M costs, provide valuable guidance as to the most economic development approach to be adopted when spate improvement projects are being planned.

ASSESSING THE BENEFITS OF SPATE IRRIGATION DEVELOPMENT

Integrating risk management in the design of spate systems

Part of the explanation of the high cost of some spate-irrigation projects has been an approach of developing fail-safe, even if costly, and sometimes not very efficient options. Instead, in comparing costs and benefits of spate irrigation, it may be useful to use a different planning horizon, rather than the 20–30 year period common to water infrastructure projects. Water users may have a different planning horizon, and may be willing to accommodate more risks in line with the uncertain, variable and dynamic nature of spate irrigation.

In spate irrigation, the concept of infrastructure and the associated notions of permanency over the relatively long engineering life of hydraulic structures need to be reconsidered. A mixture of improved soil and water management, and low-cost investment in diversions with a short, useful life may be preferable to the high-cost approach, provided they translate into a reduction in terms of the farmers' labour involved in the frequent rebuilding of intakes. This approach is closer to the traditional system of managing spate irrigation, and links better with existing water allocation rules, the disruption of which affects the degree of solidarity among the water users.

Another justification, calling for a better assessment of the relation between risk, costs and benefits, lies with the hydrology of arid areas where spate irrigation takes place. Typically, as discussed in Chapter 3, arid zone hydrology is characterized by very large variations in the number and intensity of floods. While the statistical distribution of floods varies from one place to another, it is not infrequent to experience major floods with a 4 to 5 year return period. A careful study of the return period of major floods, and an analysis of the costs and benefits associated with different levels of security, may show there is no scope in seeking to control a 50 or 100 year flood. Rather, the design of improvement interventions should follow the philosophy of spate systems and seek an intermediate level of control that offers best cost-effectiveness. The combination of permanent headworks with a fuse bund that needs to be reconstructed every 4–5 years is an example of such trade-off.

Taking into account broader livelihood and environmental impacts

Investments in spate irrigation often have significant social and/or environmental benefits, including:

- **Poverty alleviation** for a large number of households, who cultivate relatively small spate-irrigated areas as owner-operators and/or sharecroppers, derived from improved agricultural production and/or livestock activities.
- **Improvement of food security** for the number of months that farming households can satisfy their food consumption in normal years.
- **A multiplier effect** because more money enters the local economy as a result of the involvement of the local labour force, artisans and contractors in the execution of the construction works as well as an increase in the marketing and processing of agricultural and livestock produce.
- **Creation of temporary labour opportunities** during the execution of construction works as well as more permanent labour opportunities in the agricultural sector because of the increased cropped area and/or cropping intensity, especially for landless households and farming households with small plots.
- **Reduction in seasonal migration** as the need to migrate to areas in search of labour is reduced because of higher incomes from spate-irrigated agriculture and/or livestock keeping.
- **Reduction in the cutting of trees** as the need to earn an additional income from the sale of fuelwood or charcoal decreases, because of higher incomes from spate-irrigated agriculture and/or rearing livestock.
- **Reduction in the cutting of trees and shrubs** as fewer are required for the frequent reconstruction of the traditional diversion structures and any other irrigation infrastructure; and
- **Maintenance of the integrity of the land alongside ephemeral streams** that, if not managed under spate irrigation, would easily be subject to braiding and river erosion.

Spate irrigation always takes place in precarious environments – arid and remote. There are often very few options for generating income. The most common livelihood strategy is the diversification of the household economy. In addition to a highly variable income from spate-irrigated agriculture, households may have one or more source of income from keeping livestock and wage labour and, to a lesser extent, from the sale of handicraft products. The assessment of the feasibility of investments in spate irrigation, thus, should not be based only on the direct economic benefits derived from agricultural production, but also on the social and environmental benefits that may be obtained. As it is not always easy to quantify the potential social and environmental benefits of various options, they should, as a baseline, be given scores in accordance with the probability that these benefits would be achieved, and project assessments should use this ranking in selecting the preferred options. In addition, it may be useful to explore different ways of valuing capital in investments that have an explicit poverty alleviation objective.

The functioning of spate systems in many areas is a matter of survival. When the spate system fails, the only option for spate framers is migration, and with it the unravelling of a livelihood system. In assessing the benefits of spate irrigation, the fact that needs to be taken into account is that farmers and livestock keepers in these areas often have no viable alternative means of support. Hence the impact of sustaining and supporting such natural resource systems differs from investments, where the main target group has access to alternative livelihood opportunities. To illustrate this point, and the broad impacts on livelihoods of the failure of traditional spate systems, which might often correspond to a ‘no project scenario’, a social assessment of two years of drought in Balochistan 1998–2000, is summarized in Box 9.3.

BOX 9.3

Social assessment of two-year drought in Balochistan (1998–2000)

- A sharp decline occurred in the consumption of nutritious items as well as staple food intake. In many instances, the people substituted their normal food items with inferior items. For instance, 33 percent of villages reported a reduction in staple food quantity, 57 percent villages reported reduction in nutritious items such as meat, milk and ghee, and 66 percent of the villages reported substitution of normal food items such as sugar with inferior items such as raw sugar (*gurr*) during 2000.
- There were many instances medical treatment was postponed because of cost. During 2000, 47 percent of the villages reported switching over to herbal medicine; up from 9 percent in 1999.
- Purchase of new clothes and footwear declined from 52 percent in 1998 to 36 percent in 1999 and fell to 11 percent during 2000.
- A sizeable dropout rate was noted from educational institutions in the villages surveyed. The main reasons were the increased demand for domestic and productive labour and the cost of education. In 2000, the dropout rate of 71 percent was related to the increased demand for labour and 29 percent stated inadequate means of support. Both these conditions were a direct outcome of acute water scarcity during this period.
- There was a sharp decline of the area under annual crops such as wheat, millet, sorghum, vegetable and alfalfa. This occurred in 90 percent of the surveyed villages in 1998 while 10 percent of the villages reported no annual crops in this year. During 1999, respondents from 28 percent of the villages reported a further decline in the cropped area and 72 percent reported no crop at all. All the villages reported no annual crop in 2000 because of failure of rainfall.
- Reduction/de-stocking of livestock occurred in 33 percent of villages during 1998, in 90 percent of villages in 1999, and in 48 percent of villages in 2000.
- During 1999, people in 24 percent of the villages in the study area took production loans, while in 2000 the ratio of villages where such loans were taken, was 14 percent. Consumptive loans were taken in 43 percent of villages in 1998, 95 percent of villages in 1999 and 76 percent of villages in 2000. In about 14 percent of the villages, people were refused loans by the lenders because of defaults on the previous borrowing. At the community level, wealth redistribution mechanisms such as religious and voluntary charity ceased to function.
- In Qila Saifullah District, migration occurred in 90 percent of the villages ranging between 5 and 54 percent of total village households. This phenomenon occurred in 80 percent of the villages ranging between 11 and 48 percent of total village households in Mastung. Emigration seriously affected village decision-making mechanisms.
- Finally, large-scale changes in primary economic activities: dependence on agriculture as a main source of subsistence decreased from 80 percent of the surveyed population to 38 percent in Qila Saifullah, and from 80 percent to 6 percent in Mastung. Similarly, the percentage of people depending on labour as their main economic activity increased from 7 to 32 percent in Qila Saifullah and from 9 to 42 percent in Mastung.

Chapter 10
Spate irrigation in the context of river basin resource management

SUMMARY

It is important to place the development of spate irrigation in the context of river basin management. If it is well designed and managed, spate irrigation systems can fulfil several important functions in basin management, beyond providing water for agriculture, rangeland and local forestry. They include:

- preserving biodiversity;
- mitigating flood peaks;
- stabilizing river systems; and
- recharging groundwater.

On the other hand, ecosystems in arid and semi-arid regions are generally precarious. Careful consideration must be given to the possible effects and impacts of the development of spate irrigation systems on natural resources as well as on water quality and quantity.

Spate irrigation is closely linked to biodiversity and natural vegetation. Spate systems are depositories of local biodiversity – collecting seeds from a large catchment and depositing them in moist soils – and may feed ephemeral wetlands that are rich in species. Natural species of vegetation are often of considerable value and may provide an additional source of income to local communities. Grasses and shrubs, for instance, sustain livestock populations, while trees are used for various purposes. In some places, the introduction of alien species, such as mesquite, can negatively effect spate-irrigated land and represent a major problem.

The clearing of land of trees and shrubs close to spate-irrigated areas is primarily associated with the traditional construction of diversion bunds and the collection of wood for fuel. Thus, options to reduce the unsustainable use of local trees and shrubs, through the construction of more permanent diversion structures, should be highly promoted.

Much effort in spate irrigation is placed on stabilizing wadi reaches to ensure the continuous supply of water to fields. The viability of spate irrigation systems, as a means to help stabilize river systems, should be acknowledged and promoted. In particular, the use of natural vegetation, specifically planted for river training, should be encouraged because of its lower costs and the advantage of its being environmentally acceptable.

In spate-irrigated areas, the risk of sand dune formation is ever present. Dune formation particularly threatens the fringes of spate systems. The formation of sand dunes surrounding spate-irrigated areas can be exacerbated when agriculture stretches into marginal areas or when unsustainable agricultural practices in

rainfed farming include systematic clearing of land of roots and natural vegetation. The rehabilitation of sand dune areas requires the engagement of farmers to plant native trees and dwarf shrubs and to reduce agricultural encroachment on fragile land.

To a certain extent, the development of spate irrigation can contribute to flood mitigation by reducing the likelihood of large floods. There is an upper limit to this, however: spate systems intercept moderate to medium flows while peak floods are usually passed on down the wadi and may still create havoc downstream. Through their effect on the stabilization of ephemeral streams, spate systems can help avoid unexpected downstream breaches. Some interesting experiences of flood spreading have been tested and can help mitigate the damage caused by major floods while contributing to groundwater recharge locally.

The relation between spate irrigation and groundwater is complex. Spate irrigation offers opportunity for *in situ* groundwater recharge but, at the same time, reduces possible recharge downstream. The balance of opportunities and costs is site-specific, and a careful assessment of potential and constraints of groundwater use and recharge needs to be done to understand the implications of proposed spate-related interventions. In particular, most of the water diverted onto the land by spate irrigation is accounted for by evapotranspiration, and the proportion of groundwater recharge is less. When designing spate irrigation systems, a careful assessment of the changes in water balance must therefore be performed at the level of the river basin to understand the implications on the overall hydrology of the wadi.

Of particular relevance is the potential impact of spate diversion on the recharge of major aquifers in alluvial fans and in downstream plains where water productivity, through groundwater-based irrigated agriculture is, in most cases, much higher than in spate irrigation. This raises the issue of the relationship between upstream and downstream water users. Conditions, where downstream users would take greater advantage of water used by upstream spate farmers, could be the foundation for negotiations based on the concept of payment for ecosystem services, where part of the gains obtained from additional recharge downstream could be used to compensate upstream farmers for losses incurred related to reduced water supply.

On the other hard, groundwater development in spate systems has the potential to considerably modify agricultural practices and can sustain highly productive farming. Where groundwater is available, the unpredictability associated with spate irrigation disappears, and farmers can rely on a safe supply of water for their production. Wherever groundwater development has been possible, farmers have taken advantage of it and harnessed water in a more productive way than that expected from traditional spate systems. Some estimates show that groundwater-based irrigation is six times more productive than spate irrigation. Where recharge is possible, according to local aquifer and terrain conditions, it should therefore be considered as an integral part of the design of spate projects.

The reliability of spate irrigation would be greatly increased if water from flood peaks could be stored in reservoirs and then released when needed for irrigation. A conventional response to the unpredictability associated with spate irrigation would be to store floodwater in dams upstream of irrigation schemes. However, in arid environments dominated by extreme flood events and high sediment load, such an option is, in most cases, not feasible. Reasons include rapid siltation of reservoirs, the negative affect groundwater recharge and water users downstream and a high rate of unproductive evaporation from the reservoir. Wherever possible, options that effectively enhance aquifers' recharge should be preferred, as they score better both from the viewpoint of cost as well as effectiveness.

LINKING SPATE IRRIGATION AND NATURAL RESOURCE MANAGEMENT

This chapter describes the linkages between spate irrigation and natural resource management in the river basins of which spate systems are part. Ecosystems in arid and semi-arid river basins are generally fragile, and they have limited capacity to adjust to changes. If the usage of natural resources, such as land and water, is changed, the environmental consequences are often greater than foreseen. Consideration should be given to the possible effects and impacts of the development of spate irrigation systems on the available natural resources as well as water quality and quantity. Spate irrigation systems are very much part of these natural resource systems and are themselves affected by changes in the land and water resources in the river basins.

It is important to place the development of spate irrigation in the context of river basin management. Spate irrigation systems, when they are well managed, fulfil several important functions, beyond the spate irrigation per se: preserving biodiversity, mitigating flood peaks, stabilizing river systems and recharging groundwater. These spate irrigation system functions of are often influenced by other development activities elsewhere in a basin. The complexity of interaction between spate irrigation and other development activities on the one hand and the river ecosystem on the other is well illustrated in the case of the Manchar Lake in Sindh province of Pakistan. The lake is formed by spate flows maintaining several extra functions beyond the spate irrigation. It used to be an excellent example of flood management and surplus floodwater. Moreover, it served biodiversity, drinking-water, fisheries and was an abode of indigenous communities. The lake, however, witnessed a downturn after contaminated agricultural drainage water, from a perennial irrigation system in the upper reach of the basin, was routed to the water body.

Linkages between spate irrigation and natural resource management in the river basins, the effects that river basin management have on spate irrigation and the impacts of spate irrigation on river basin, management are summarized in Table 10.1.

NATURAL VEGETATION AND BIODIVERSITY

Ephemeral rivers are often unexpectedly rich depositories of vegetation. Spates collect seeds from a large part of catchments and deposit them in the river bed and flood irrigated fields. The moist, and often organic-rich layers of silt forming spate irrigated fields, provide a favourable environment for wild trees, plants and mushrooms to germinate and develop. Logs and branches, often carried over considerable distance by spate flows, may add to this process by lodging against trees growing in or along the river channel, creating small blockages, trapping organic material, and further supporting vegetative growth *(Jacobson et al., 1995).* Spate irrigated areas have ecosystems with a great biodiversity of plants and animals, in particular birds. In Balochistan (Pakistan), spate flows have contributed to the development of wetlands, which are an excellent refuge for migratory birds *(Nawaz, 2002).*

Temporary wetlands in dry areas, such as ephemeral ponds, often have a considerably high biodiversity, especially freshwater wetlands *(Brendonck and Williams, 2000).* Biodiversity is very much related to the duration of the aquatic phase, especially amongst crustaceans. The species richness in arid-area, temporary wetlands can be higher than in permanent temperate or humid-zone wetlands. Wetlands in arid areas contain considerable 'hidden' biodiversity in the shape of egg banks of multiple species, that often make it possible for species to survive weather variability or the early drying of ephemeral pools. The spate fields, lakes and ponds are an excellent abode for these highly important species. Moreover, birds favour spate fields where organic agriculture is practised and where they are least disturbed.

TABLE 10.1
Linkages between spate irrigation and natural resource management

Issue	Impact of spate irrigation	Impact on spate irrigation
Biodiversity and natural vegetation	• Spate systems are depositories of local biodiversity.	• Wild plants and trees are often additional sources of income. • Mesquite infestation has a negative affect on use of the command area.
Catchment degradation	• Cutting of trees for traditional diversion structures may contribute to the degradation the catchment area.	• Catchment degradation changes runoff patterns and increases sediment loads.
River morphology	• Spate systems tend to stabilize river morphology. • Encroachment on river banks creates vulnerable areas.	• Catchment degradation and cutting of riverine forest and bank vegetation causes changes in runoff regime and may trigger scouring and widening of wadi beds.
Dune formation		• Dune formation particularly threatens the fringes of spate systems.
Flood management	• Spate systems usually intercept moderate to medium flows, only large floods are passed on down a wadi.	• Major floods change river morphology and affect viability of spate systems.
Groundwater recharge	• May be either positive or negative. May increase recharge by slowing down flood flows. May decrease recharge by extracting water from the wadi and increase evaporation • Cutoff structures may obstruct subsurface flows that are the major source of groundwater recharge.	• In areas where groundwater is available, conjunctive use of groundwater and spate flows can sustain highly productive agriculture.
Upstream and downstream water use	• Spate irrigation may reduce water availability for downstream use.	• Intensification of upstream water use may change water availability for spate irrigation

Natural species of vegetation are often of considerable value. A sample of native species occurring in the spate-irrigated area of DG Khan in Pakistan and their productive uses is given in Table 10.2. Grasses and shrubs, for instance, sustain livestock populations, while trees are used for various purposes. Tamarix trees are used for fuel, utensils and tanning, while acacia is used as timber, fuelwood and for the construction of protective fences. Ziziphus is a typical multi-purpose tree as it provides fodder, fuelwood, timber and fruits, while it is also used for medicinal purposes and beekeeping. In many countries, such as in Pakistan, the dwarf palm is used for the production of mats, ropes and sandals. In the spate-irrigated areas of Pakistan, the harvesting of various types of mushroom is a lucrative activity, with truffles fetching particularly good prices. The spates also carry wild vegetables and cucurbits to the fields. During years when the harvest is poor, natural vegetation can help families survive these adverse periods.

There is considerable variation between spate systems with respect to the degree of natural vegetation that occurs. The spate systems in the Tihama in Yemen are largely devoid of natural vegetation, while there is a great diversity of wild vegetation in those of Ethiopia, Pakistan and Sudan. In extreme cases, there are spate irrigation systems where natural vegetation grows out of control. In the spate irrigation systems of the Gash and Tokar in the Sudan, there has been a severe invasion of mesquite (P*rosopis jutiaflora and*

Prosopis chilensis) since the 1990s *(FAO, 2000)*. The species were introduced as part of dune stabilization programmes, but soon got out of hand. The aggressive spread of the mesquite in the Gash and Tokar spate systems in the Sudan is largely the result of poor field and marginal land management arrangements, related to the absence of permanent land ownership in these systems. The mesquite is a prime source of income for landless families, who use it to produce charcoal.

Under the new Gash Livelihoods Project, the eradication of mesquite is now foreseen in combination with land titling. This will need due consideration of mesquite's economic importance as the primary source of cash income, particularly for the landless, and its river bank stabilization effects. The project will identify suitable alternative non-invasive tree species for establishment on public lands and women's group woodlots in the area. Such tree species will include nitrogen-fixing trees as well other trees with extensive root systems.

TABLE 10.2
Native tree species and economic uses in Suleiman spate-irrigated area (Pakistan)

Botanical name	Common name	Economic uses
Acacia kacquemonti	Kikri	Leaves browsed
Acacia nilotica	Kikar	Timber, leaves browsed
Aerva javanica	Bui	
Alhaji camelorum	Jawan	Weed
Aristada depressa	Lumb	Grass (poor quality)
Calligonum polygonoides	Phog	Sand stabilizer
Capparis deciduas	Karir	Firewood, browse
Carex sp.		Palatable grass
Cenchrus biflorus	Lidder	Weed
Cenchrus ciliaris	Dhaman	Palatable grass
Cenchrus pennisetiformis	Lidder	Low-quality grass
Crotalaria burhia	Chag	
Cymbopogon jawarancusa	Khavi	Medicinal value
Cymbopogon schoenanthus	Khavi	Low quality grass
Cynodon dactylon	Khabbal	Palatable grass
Desmostachya bipinnata	Dab	Low quality grass
Dichantium annulatum		Palatable grass
Diptergium glaucum	Fehl	Palatable grass (camels)
Eleusine flagellifera	Chimber	Low quality grass
Euphorbia spp.		Browsed
Haloxylon recurvum	Khar	Browsed (camels)

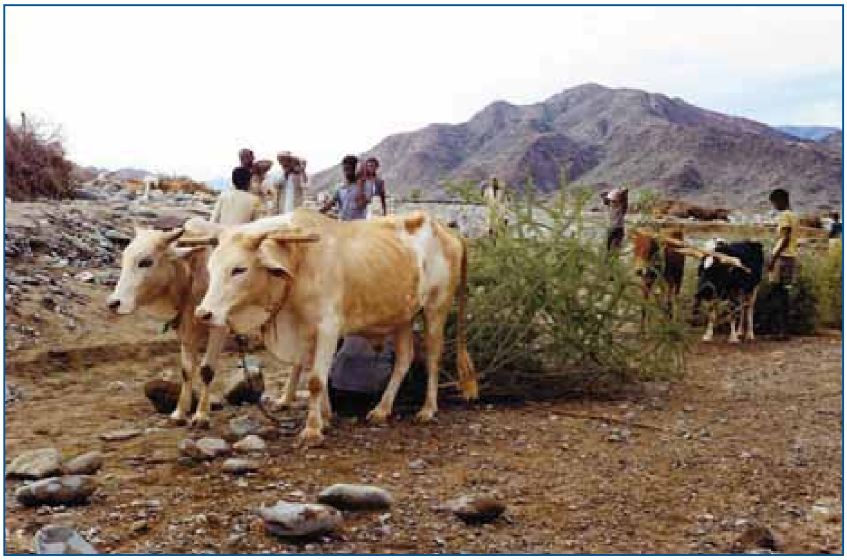
Botanical name	Common name	Economic uses
Haloxylon salicornicum	Lana	Browsed (camels)
Indigofera oblongifolia	Jhil	
Kochia indica	Bui	Low quality shrub
Lasiurus sindicus	Ghorka	Palatable grass
Leptadenia pyrotechnica	Khip	
Panicum antidotale	Murat	Palatable grass
Panicum turgidum	Murat	Low quality grass
Peganum harmala	Harmal	Medicinal value
Phoenix dactylifera	Khajoor	Fruit tree
Poa spp.		Palatable grass
Prosopis cineria	Jand	Timber, browse
Prosopis juliflora	Mesquite	Firewood, browse
Rhazya stricta	Senhwar	Medicinal value
Saccharum munja	Sarkanda	
Salsola foetida	Lani	Browsed (camels)
Salvadora oleodis	Wan	Browsed
Suaeda fruticosa	Lana	Browsed
Tamarix aphylla	Frash	Sand stabilizer, utensils
Tribulis terrestris	Bhakara	Weed
Withania coagulans	Paneer	
Zizyphys Mauritania	Ber	Timber, browse, honey forage
Zizyphys nummularia	Mallah	Browsed

Source: PARC/UNEP/NESCAP 1994

CATCHMENT DEGRADATION

The construction of brushwood spurs and weirs in traditional spate irrigation requires large numbers of trees and branches. Because of its multiple properties, acacia branches are preferred. The intensive use of acacia trees seriously threatens the long-term sustainability of spate irrigation in the Eastern Lowlands. For example, it has been reported that more than 28 000 trees are required annually in the 3 000 ha system of Sheeb in Eritrea (see Figure 10.1 for shrubs collection in Eritrea). Farmers estimate that it now takes ten times longer to gather the acacia shrubs needed to maintain their system than in the past. Similarly, in the border area of the Sudan with Eritrea, brushwood flood-spreading structures were traditionally built from branch palm (*Hyphaene thebaica) (Niemeijer, 1993).* This tree has now largely disappeared from the area and the steep decline in water spreading is associated with its loss. In several parts of Ethiopia natural vegetation has become scarce and the sorghum roots are excavated and used in place of brushwood for flood diversions, with further negative consequences on soil fertility and erosion.

FIGURE 10.1
Collection of shrubs for the repair of flood diversion spurs in Eritrea



Desertification of the areas close to irrigated areas is associated with the construction of diversion bunds and the collection of wood for fuel and construction. Many other factors cause deforestation and land degradation in the upper catchment areas where spates flows are mostly generated. These include the expansion of agriculture and overgrazing driven by rising populations, and the breakdown of indigenous terracing and other erosion control measures *(Scholte et al., 1991)*.

RIVER MORPHOLOGY

Spate irrigation occurs either in mountain valleys, or in the plains close to the mountain front often at the end of a gravel fan. Particularly in the latter areas, wadis tend to be unstable. Spate farmers attempt to stabilize these sections of the wadi to ensure a continuing supply of water to their spate irrigation schemes. Changes in the river morphology may originate in the lack of protection of local vegetation, i.e. the cutting of riverine forests or of riverbank vegetation. Changes are triggered by historic floods that usually result in a general lowering of river bed levels. The construction of flood canals at unsuitable sites may also increase the degradation process, as the river may change its course during a large flood.

There is usually a gradual transition in the vegetation along spate wadis. The upper reaches experience more frequent floods, and the physical disturbance that comes with them removes the vegetation. In the lower reaches, discharge decreases as a result of upstream abstractions and infiltration to the wadi beds. Infrequent floods result in harsh environments where only hardy drought-resistant plants can survive *(Jacobson et al., 1995)*. Vegetation can be used as an indicator to assess the pattern and reliability of flooding.

The vegetation that develops in ephemeral river beds also plays an important role in their stabilization. This is particularly true in spate wadis in alluvial plains, which do not have beds armoured with gravel and cobbles, and are prone to scour. While the degradation of the ephemeral river bed is often a natural phenomenon, its speed and intensity can be increased by human action, such as the cutting of trees and bushes in and along the river bed as well as the degradation of wadi catchments.

Degradation of an ephemeral river bed may advance to such an extent that canal intakes are left far above the wadi bed and that diversion becomes impossible. An example is the Yanda-Faro River in Konso in Ethiopia. It was reported that the historic *El niño* floods that occurred in 1998 resulted in a rapid degradation of the river beds in the region and the erosion of the riverbanks *(Farm Africa, 2003)*. The cutting of vegetation and free cattle grazing in a downstream riverain forest was among the factors that caused the Yandefero River to change course and discharge into a lower section of the main river. The result was a continuous degradation of the river bed over a length of 10 km, which rendered many existing upstream intakes unserviceable (Figure 10.2).

FIGURE 10.2
Lowered river bed and eroded river banks causing the abandonment of the canal head, Ethiopia

Wadi beds move up and down in response to the flood pattern experienced. Abandoned intakes and canals, that can no longer be used, are often seen in the older spate-irrigated areas. Farmers in Barag in the south of Balochistan, Pakistan, for instance, had to abandon their existing diversion structure in the 1980s because of the degradation of the river bed *(Halcrow, 1993)*. The recent history of the Korakan River in Balochistan, Pakistan illustrates the impact of the degradation of the river bed on the livelihoods of many households. Until the early 1970s, about 2 000 households living in 30–40 communities depended on 11 collective diversion bunds and a large number of individual structures for the irrigation of their fields on both riverbanks. As a result of the cutting of trees and overgrazing of vegetation in and along the river bed, the degradation process started in the downstream reach of the river at the beginning of the 1970s. Between 1976 and 1989, 7 of the 11 bunds could not be rebuilt by the farmers as the level of the river bed was too low and the river too wide. As a result, many fields could not be irrigated for many years and their owners migrated to other areas *(Halcrow, 1994).*

Vegetation sometimes helps in raising the river beds. When trees, such as tamarix, colonize the bed of spate rivers, flows are slowed down, sediment settles and bed levels rise. In many rivers prone to degradation, as in wadi Tuban and wadi Siham in Yemen, as well as in Korakan River in Balochistan, a ban on cutting vegetation along the wadi bed has been put in place by the spate irrigation farmers. In other areas, farmers have actively planted tamarix saplings. In Balochistan several projects have planted different trees and shrubs including tamarix along the banks and inside the rivers for multipurpose functions. This was done on a participatory basis on the request of local farmers and villagers.

Not only does vegetation withstand normal floods, but regeneration is possible from regrowth when damage occurs during exceptional floods. Sediments deposit in front, over and behind the vegetative barrier. Sedimentation of coarse material, during high and medium floods and of silt mixed with vegetative debris at low flows, eventually forms a solid natural protective structure.

The distribution of natural vegetation in wadis is, however, limited to sites of low-speed flow, where seeds are deposited and covered with enough sediment to obtain germination. In sites characterized by swift currents, vegetation establishment can only be obtained by planting cuttings deep and offering protection against scouring.

WIND EROSION AND SAND DUNE FORMATION

In many spate irrigation systems, the risk of sand dune formation is ever present. A study by FAO using aerial photography dating from 1976 and 1987 for Wadi Zabid in Yemen suggests that 5 percent of the productive area was lost to sand movement in that period. One reason why spate irrigation faces the threat of sand dune formation is that agricultural land stretches increasingly into marginal areas, with little accessibility to spate flows and poor (sandy) soil textures. Another explanation may be related to the practice of rainfed agriculture in the sand dune areas. In some places, when there is adequate rainfall for rainfed agriculture, farmers tend to uproot natural vegetation and crop marginal, sandy land. Animals graze the area after the harvesting of millet and, as a result, the sand dunes are stripped of natural vegetation and regeneration becomes slow and difficult *(Scholte et al., 1991).*

The rehabilitation of sand dune areas requires the engagement of farmers in planting native trees and dwarf shrubs. In the Tihama (Yemen), a dwarf shrub (*Dipterygium glaucum*) and two tuft grasses (*Pannicum turdidum and Odysseum mucronatum*) form the vegetation cover that will eventually stabilize the sand dunes *(El-Hassan, 1999)*. Management of the rehabilitated land is crucial and cultivation and grazing should be limited, if not prevented. This can only be done with the full participation of local populations.

Another closely related problem is wind erosion. In dry plains, wind erosion tends to remove the finer particles of soils, causing loss of soil fertility. Watering of soil through the continued use of the spate systems is the best strategy to minimize these impacts.

FLOOD MANAGEMENT

The role that spate irrigation can have in flood mitigation is often overstated. In Pakistan, for example, the development of spate irrigation systems has been advocated because it would help reduce damage to the large perennial canals on the western side of the

Indus irrigation system. The hill or mountain torrents have at times caused considerable damage to the large-scale perennial irrigation systems. Studies commissioned by the Federal Flood Commission in Pakistan explicitly envisage the dual objective of spate-irrigated agricultural development in the piedmont plains and the protection of perennial irrigation infrastructure such as the Chasma Right Bank Canal, the Dera Ghazi Khan Canal, the Flood Protection Bund Complex and the Pat Feeder Canal *(NESPAK, 1998).*

Yet, the contribution that development of spate irrigation can make to flood mitigation is limited and, in general, there is little experience in managing spate irrigation systems for flood mitigation. The extreme floods are those that cause the most damage and they are only marginally mitigated by spate irrigation systems since spate irrigation makes prevailing use of low and medium floods. Still, widespread development of spate irrigation in the catchments and tributaries or the larger wadi systems can reduce the chance of large floods building up. Simple hydrological models, based on the flood assessment methods described in Chapter 3, can provide rough estimates of possible impacts of spate irrigation on floods. Spate irrigation systems also tend to stabilize ephemeral streams, which avoids unexpected breaches downstream.

A related technique for flood mitigation is that of flood spreading. Experimental work has been done in Iran by the Soil Conservation and Watershed Management Research Institute. Starting with a pilot project at the Gareh Baygon Plain, a number of measures were implemented on 60 000 ha of land. The main purpose was the spreading of floodwater for recharge on alluvial fans, reviving the vertical well systems (*qanats*) and encouraging the development of new wells. Part of the water was used for spate irrigation. In flood spreading, water is diverted from the bed of an ephemeral river, channelled through a desilting basin and spread over a number of bunded fields. The bunds run along the contours, and channels collect the excess water and pass it down to the next contour bunds. Eucalyptus and acacia trees are planted in the water spreading area. At the bottom of the spreading area, water is collected and diverted back into the river. Good results are claimed with this technique, both for recharge and flood control. It was estimated that the damage produced by a large flood in Gareh Baygon spreading area represented only 2.5 percent of the cost that would have been incurred downstream had the flood flows not been captured by the flood spreading system.

In Balochistan, when floodwater is in surplus, it is diverted to specific locations for collection into ponds used for domestic and animal drinking-water. These sites are preferential groundwater recharge areas. Upon drying of ponds, villagers dig shallow wells inside and around ponds to collect water.

INTERACTION BETWEEN SPATE IRRIGATION AND GROUNDWATER

The relation between spate irrigation and groundwater is complex. Spate irrigation provides the possibilty of in situ groundwater recharge, but also reduces the chance of recharge downstream. On the other hard, groundwater development in spate systems may considerably modify agricultural practices and can sustain highly productive farming. The balance of opportunities and costs is site-specific, and a careful assessment of potential and constraints of groundwater use and recharge should be done to understand the implications of proposed spate-related interventions.

Groundwater recharge

Two types of aquifer are important in spate-irrigated areas. In the valleys, alluvial sediment deposits consist of generally unsorted, but coarse and uncemented material with high permeability. The deposits are found in a strip along the river bed, which may vary in width from a few meters to a few hundred meters. Strip aquifers have very favourable recharge conditions and are mainly recharged from the infiltration of spate flows and seepage zones along the wadi bed. Because of their small volume, and high permeability, the strip aquifers are quickly depleted. Another type of aquifer is found further downstream, at the level of the alluvial fans and in the plains. They are actively recharged by the floods in the wadis and may be several thousand metres thick. They may not be homogeneous and consist of a number of independent groundwater flow domains, with their own recharge and discharge zones and with varying water quality *(Van der Gun* and *Ahmed, 1995)*. In many areas, horizontal wells (*foggara* or *qanats*) are developed in the spate recharge zones. Many of these aquifers are intensively developed.

In general, aquifer recharge occurs mainly through infiltration in the wadi beds rather than from channels and fields. While recharge may be enhanced by spate irrigation, where diversions flatten the river slopes and reduce flow velocities, and diversion bunds produce ponding, most of the water diverted onto the land is accounted for by evapotranspiration, and the proportion of recharge is less. When designing spate irrigation systems, a careful assessment of the changes in water balance in the river must therefore be performed to understand the implications of spate diversion on the overall hydrology of the wadi. Results will vary from one site to another, as a function of the characteristics of the floods and of the aquifers. Of particular relevance is the potential impact of spate diversion on the recharge of major aquifers in the alluvial fans and in the plains where water productivity through groundwater-based irrigated agriculture is, in most cases, much higher than in spate irrigation.

FIGURE 10.3
Recharge weir in Hadramawt, Yemen

Options for groundwater recharge also exist beyond spate systems. An unusual and highly innovative recharge structure was constructed by farmers in Wadi Hadramawt in Yemen (Figure 10.3). The structure consists of 1 m high lime-mortar wall across the river that serves to slow down and spread the flood to maximize recharge. Another important practice is to leave the stone armouring of wadi beds intact, as the presence of large stones and boulders reduces the water velocity and encourages river bed recharge.

The ephemeral wadi beds carry a substantial subsurface flow, which is often the main source of aquifer recharge. Caution is needed not to interfere with these subsurface flows through cutoff weirs or impervious bed stabilizers, as downstream well water supplies may depend on these flows for their recharge. An example of a spate irrigation project gone wrong in this respect is the Wadi Siham in Yemen. The weir was cutting-across the traditional flood channels, blocking the subsurface flow in the river, and depriving a large number of downstream well owners of their source of water.

Groundwater use in spate schemes

Access to groundwater in spate irrigation radically changes farming opportunities. Where groundwater is available, the unpredictability associated with spate irrigation largely disappears, and farmers can rely on a safe supply of water for their production. Wherever groundwater development has been possible, farmers have taken advantage of it and harnessed water in a much more productive way than that expected from traditional spate systems.

Since the modernization of the Wadi Zabid system in Yemen, the area under cultivation has increased substantially. There is evidence that this is related to the increase in groundwater use, rather than any increase in the diversion efficiency provided by the new structures in the spate-irrigated areas. In Wadi Zabid, wells are used in conjunction with spate-water supply and as the only sources of irrigation water. Since the 1970s there has been a rapid increase in well development, mainly shallow wells with some extensions. In 1988, there were 1 411 wells in Wadi Zabid, of which 1 221 were functional. These were almost all used for irrigation but, at the same time, served as an important source of drinking-water. As a result, the area under banana has increased from 20 ha in 1980 to more than 3 500 ha in 2000. Similarly in Wadi Tuban in Yemen, agricultural production has changed dramatically since the 1980s mainly because of the remarkable increase of shallow wells; about 2 300 ha are now under high value vegetable production.

Groundwater quality in the coastal region of Yemen where Wadi Zabid and Wadi Tuban are located, is generally good enough for irrigation, unlike that in spate areas in Eritrea, Pakistan and Tunisia. In wadi Labka, Eritrea for instance, groundwater salinity ranged from 2 250–2 650 µS/cm. In areas with high salinity, irrigation from groundwater is not an option. However small prisms of freshwater, stored in the bed of the spate rivers, can be an important source of drinking-water supply in areas with generally saline groundwater.

The intense use of groundwater, and the higher water productivity associated with groundwater-based irrigation, raises questions on the relation between spate irrigation and groundwater recharge. One issue, related to in situ water management, is whether the best spate-water management strategy should maximize recharge, or agricultural productivity of the spate-irrigated areas. Another issue is the relationship between upstream and downstream water users. It is exemplified by the recent debate on water distribution in Wadi Zabid in Yemen, where a system of time-based water allocation is in place. Under this regime, the downstream command area is entitled to floods in the off-season only. As the occasional spate flows are able to recharge shallow aquifers for a long time, downstream land users are now requesting their share of spate floods in the peak season. Such conditions, where wealthier downstream users would take advantage of water used by upstream spate farmers, could be the basis for application of the concept of payment for ecosystem services, where part of the gains obtained from additional recharge downstream could be used to compensate upstream farmers for losses incurred with reduced water supply.

WATER STORAGE AND DAMS

The reliability of spate irrigation would be greatly increased if water from flood peaks could be stored, and then released when needed for irrigation. This makes the construction of small dams a very popular activity in semi arid areas. However, the benefits to local communities for irrigation and groundwater recharge, need to be balanced by the adverse impacts on downstream spate water users. Hydrological studies on Wadi Zabid and Wadi Tuban in Yemen suggest that in the 1990s the inflow to the spate irrigation areas may have reduced by about 30 percent and the reduction was attributed to the development of a large number of small dams in the upper catchments *(IIP, 2002).* These upstream developments change the runoff pattern, with low flows and the earlier parts of the flood wave being intercepted by the dams, while downstream systems receive the large floods that cannot be retained. This can have an impact on diversion efficiencies in the downstream spate systems as most of the water resource in spate rivers flows in the range of low- to medium-discharge.

Besides the upstream-downstream issue, dams are rarely an option in arid areas because of the rapid siltation rates that occur when they are supplied by floods carrying very high sediment loads. Dams with a very large initial capacity would be needed to provide enough storage for sediment deposits to achieve a reasonable economic life. The use of dams in the spate-irrigated areas in Eritrea, where sediment loads can be as high as 10 percent by volume, has been ruled out as an option for this reason, moreover, dams in the Rif Mountain in Morocco suffer from rapid siltation. Another example is the Gomal Zam dam in DI Khan in Pakistan. A series of feasibility studies have highlighted the heavy sedimentation, which threatens the longevity of the dam, and may be detrimental to spate-irrigated agriculture downstream.

Another illustrative example is the discussion around the construction of a dam on Wadi Surdud in Yemen, one of the major ephemeral streams of the Tihama. With the present system, an extensive area, which is supplied by spate flows and well irrigation, is under high value crops. In the existing system, sediment is not a problem but rather an asset as it serves to constantly renew soil fertility. On the positive side, the dam would supply perennial irrigation water to an irrigation scheme in the upstream part of the wadi and provide protection against floods. On the negative side, downstream spate and groundwater recharge will be affected, high evaporation losses and serious sedimentation will take place, and it is expected that the dam will also trap seeds and other sources of high biodiversity and will produce relatively ‘sterile’ water at best.

Kowsar (1998) made a case for storing water in a shallow aquifer rather than in dams in semi-arid areas where spate irrigation is practised. He argues that reservoirs in Iran amount to 30 km^3 and that the cost of developing this capacity is US$0.20 per cubic meter. The total potential storage capacity in debris cones, alluvial fans and colluvial soils in Iran is 4 300 km^3, equivalent to 10 times the natural precipitation in the country. Hence, the identification of possible sites for recharge hence should not pose a problem. The cost of creating 1 m^3 of storage capacity under artificial recharge – using the model experimented in Gareh Bygone in Iran – is US$0.0008. The cost of creating 1 m^3 of water actually stored, based on average precipitation and a conservative figure of 30 percent effective recharge, would be US$0.027 even if the costs of pumping will reduce this cost advantage to some extent.

These examples show that it is important that all the impacts of the proposed investment be understood and assessed for their costs and benefits, to take economically sensible decisions. However, decisions are often driven by the tendency to respond to the water crisis by building more dams, even in situations where there may be more viable alternatives. A comparison of water resource development through spate irrigation and perennial dam-based irrigation is given in Table 10.3.

TABLE 10.3
Comparison of spate irrigation with perennial dam-based irrigation in arid areas

Spate irrigation	Perennial irrigation (dam-based)
• Supplies are insecure, but this insecurity could be reduced if spate flow is combined with groundwater irrigation.	• Supplies are secure.
• Water storage is in soil profile.	• Water storage is in reservoirs, high evaporative losses in shallow dams.
• Investment cost per m^3 of water stored is low.	• Investment cost per m^3 of water stored is high.
• Sedimentation positively contributes to soil fertility.	• Sedimentation causes reservoir siltation and reduces the useful life of the reservoir.
• Peak flows cannot be utilized.	• Peak flows can be stored.

Chapter 11
Recommendations for interventions in spate irrigation

INTRODUCTION

While spate irrigation is relatively marginal in absolute terms, it represents a valid development option for rural populations in many arid countries. By harnessing floods from wadis, it allows farmers to secure crop production and therefore contributes to food security and poverty alleviation. The benefits of spate irrigation go beyond increased productivity of water use and include increased functionality of domestic water, groundwater recharge, fodder for livestock and environmental services such as flood control and biodiversity conservation.

This chapter provides recommendations for improving or developing spate irrigation systems and is divided into three parts. The first part summarizes lessons learned from three decades of spate irrigation projects, on which this report is based, and provides conclusions on factors affecting the successes and performances of spate irrigation interventions. The second part provides general recommendations that apply to most situations and concern mostly development approaches and policy issues. Specifically, it lists recommendations particular to engineering, design and management interventions. The third part provides a more specific set of recommendations applicable to the different types of spate irrigation systems described in Chapter 1.

LEARN FROM PAST EXPERIENCE

Over the past three decades, spate irrigation development has been supported under a range of national and international programmes. The type of external support falls into one or more of the following categories:

- investment in major civil engineering to provide new spate-irrigation infrastructure;
- support to traditional systems; and
- provision of earthmoving equipment at subsidized rates.

Extensive investments have been made in large spate-irrigation systems in the 1970s and 1980s in Yemen and Pakistan and, to a lesser degree, in Eritrea, Ethiopia, the Sudan, Algeria, Morocco and Tunisia. The large-spate irrigation improvement projects have been dominated by a heavy engineering approach where numerous traditional, independent diversion structures have been replaced by one or two permanent gated diversion weirs supplying new canals. Experience with most of these projects tells that future interventions in spate irrigation should favour low-cost diversion structures and avoid sophisticated technical solutions, which have proved to be economically unjustifiable and difficult to operate properly. The main lessons learned from the experience with spate irrigation development to date can be summarized as follows:

- Investment costs for large schemes involving new permanent diversions and main canals have been high. It is clear, in most cases, that they cannot be justified in purely economic terms, by the returns from spate systems that are already diverting and using most of the available water.

- In large agency-managed schemes, the role of farmers changed from being the active irrigation managers they were in the pre-project situation to passive receivers of irrigation water, whose access to water became totally dependent upon the performance of the agencies managing and maintaining the intakes and canals.
- The operation and maintenance of the larger diversion structures and canal systems can be difficult and expensive. In particular sedimentation at intakes and in canals is often not properly controlled in modernized systems. The need for frequent canal de-silting results in excessive maintenance costs that cannot be met without continuing external support, usually from government.
- The planning and design of rehabilitation and/or improvement works in large schemes have mostly been carried out without effective partnership with farmers and land users. Farmers' knowledge of the local situation, and their preferences, regarding the scope and type of works and changes in the layout of their irrigation system, were often not properly considered during the design process.
- Economic considerations have often led to the design of diversion structures with a much lower diversion capacity than traditional ones, prompting farmers to revert to their traditional structure to take advantage of the flood peaks bypassing the new permanent intakes.
- In many cases, new and more robust permanent structures have promoted inequity in the distribution of irrigation water and led to the collapse of traditional water rights. Modernized diversion structures give much larger control over spate flows to favoured groups of the upstream farmers than traditional structures.

Experience with smaller farmer-managed systems, where incremental structural reinforcements have been introduced to improve the reliability of existing traditional intakes and reduce maintenance costs have generally been more successful and cost effective than large-scale interventions. Farmers have maintained a much higher level of ownership of their schemes and kept the overall responsibility for operation and maintenance, therefore ensuring higher level of sustainability and less dependence on external support.

Another important programme supporting the improvement of traditional structures has been the provision of earthmoving equipment to alleviate labour requirement for the maintenance and reconstruction of bunds. In such programmes, bulldozers and front loaders are made available against rates that typically cover part of the running costs but none of the capital charges. With bulldozer programmes, farmers are given new means to build or restore diversion works – especially earth bunds – or improve the command area ranging from gully plugging to repairing canal bunds to making new flood channels. In countries where bulldozer programmes are in place, they tend to be uniformly popular and have developed into the lifeline for spate irrigation.

On the downside of the bulldozer programmes is the fact that traditional water distribution systems are sometimes jeopardized because upstream farmers are able to build larger bunds. In addition, most bulldozer programmers have faced serious maintenance problems: their challenge is to have the rental price cover the total cost of running the bulldozer they also have to stimulate local entrepreneurs who rent out earthmoving equipment. Where public support to bulldozer programmes has been discontinued for financial reasons, this usually led to a major crises as farmers were no longer able to construct and repair flood bunds.

In 1992, IFAD, published a report in which it presented its experience of large spate-irrigation systems modernized with gated, permanent, diversion structures and new irrigation should favour low-cost diversion structures and avoid sophisticated technical solutions, which had proved to be economically unjustifiable and difficult to operate properly. It recommended (a) that farmers should be more involved in the development of improved spate schemes; (b) that spate-irrigation systems should be self-reliant insofar as routine operations and repair are concerned, with some backstopping from technically competent public sector units as appropriate; and (c) that governments should not be expected to provide the bulk of resources for maintenance.

In spite of these findings, and widespread adoption of the rhetoric of participatory irrigation management, not much has changed in the engineering approach applied in the recent past, in particular in relation to modernization and rehabilitation of large spate systems carried out with financial support from international partners.

DEVELOPMENT APPROACH

The selection of an appropriate development concept for spate irrigation systems of any scale requires a clear understanding and appreciation of a series of issues that are specific to the spate irrigation context. Clearly different approaches are needed for schemes with different characteristics, levels of development, access to external support from local or national governments and NGOs. However the success of any intervention in spate irrigation will largely depend upon a set of principles that are valid in all cases. These issues and principles have been discussed in details in this report and are summarized below.

Place spate irrigation within a broader development context

Alleviation of poverty in spate-irrigated areas cannot be achieved through technical improvements to spate irrigation alone (see Box 11.1).

BOX 11.1

Designing structural improvements within a broader development perspective: Example of the Gash project

The rehabilitation of the Gash spate system is an example of how a good project needs good engineering embedded into a sound development perspective. There was a strong change of emphasis in the rehabilitation of the Gash spate system in Sudan, where, since 2002, IFAD supported a sustainable livelihood regeneration project that chose to put livelihoods and institutional reform at the core of its development approach (IFAD, 2004). The main thrusts of the project were community development, capacity building and empowerment, animal production and rangeland management, control of mesquite invasion of farm lands, financial services and marketing and institutional support. Structural improvements included river training, de-silting to return canals to their original design and improvements of field layouts.

It is too soon to judge whether this approach will achieve more than the top-down approaches described earlier in this report. Initial indications are that, despite many constraints, considerable results have been obtained for equitable land distribution, security of tenure, empowerment of local communities and enhancement of livelihoods. However, poor progress with the physical rehabilitation of the irrigation system and institutional changes to management may compromise its success. A reliable water supply is the foundation of any irrigation project and must clearly be given a high priority in project design and implementation.

Water is not the only constraint to development and many poor households rely only partially on spate-irrigated agriculture for their incomes. Successful poverty alleviation will also depend upon a series of actions, among which the most frequently needed are:

- improvement of access to extension services, credit and marketing;
- improvement in livestock production – by restocking, exchanging breeds, improving fodder production and rangeland improvement, as well as the processing and marketing of livestock products;
- improvement in local forestry – by developing local agroforestry, improved marketing of non-timber produce, by uprooting invasive species;
- improved access to domestic water, both through locally appropriate facilities, wells and pumps and, where appropriate, groundwater recharge;
- flood protection measures of villages and river banks;
- creation of opportunities for wage labour and off-farm income, in particular for landless households; and
- in some cases, eradication of diseases such as malaria and tryposonamis.

While not all projects will have components covering the range of livelihood issues, these issues should be considered when projects are being planned. At the minimum, improvement projects need to be screened for their impacts on livelihoods, to ensure that unintended negative consequences are not introduced.

Two issues stand out in particular that have significant bearing on the quality of life. The first is the availability of water for domestic purposes. Where spate-irrigated areas are underlain by a shallow aquifer with freshwater, drinking-water can be supplied from village wells. This is reliable during good and normal years, but may be affected by a prolonged drought. Spate projects can have unintentional negative impacts on drinking-water downstream of diversion sites when they are not carefully designed.

Another issue, particularly in old spate-irrigation systems, is the high deposition of sediments that has raised farmland levels above the level of village areas, thus increasing the risk of flooding of the villages. Besides this problem there is the risk of riverbank breaching, damaging farmland and residential property in the process and causing the inhabitants to loose the very basis of their existence.

The production of wood and fodder and terrain stabilization all benefit from systematic efforts towards agroforestry in spate-irrigated areas. Agroforestry can be managed in several ways, including allowing natural vegetation to grow in the command area actively protecting natural vegetation. In addition planting of indigenous tree species will help stabilize bunds and river courses, and provide fuelwood and fodder. A reverse side to the promotion of agroforestry, is the introduction of new species, such as mesquite (*Prosopis juliflora*), often imported to fix dunes, which has turned into a major pest in many spate-irrigated areas, including in the Sudan (both Tokar and Gash) and Yemen, the Tihama Plain. The eradication of mesquite requires major efforts through mechanical and manual uprooting.

Livestock is of prime importance to the household economy in arid areas. Enhancement of the productivity of livestock, includes improving access to animal feed (i.e. fodder crops and spate-irrigated pastures), watering points and veterinary services, closure and management of grazing areas, as well as the processing and marketing of livestock products and restocking after a catastrophe.

Many of these issues are not gender-neutral. Women are usually in charge of domestic water fetching, they raise small livestock, prepare and sell dairy products and collect fuelwood. They are also involved in producing handicrafts for sale at local markets. All the above points are therefore of great relevance to them and a careful consideration of these issues in spate programmes can help balance benefits among women and men.

Understand the socio-economic context

An understanding of the socio-economic context and the strategies that farmers adopt to cope with the unpredictability associated with spate irrigation is essential to ensure effective and sustainable improvements to traditional spate-irrigation systems. This knowledge can help planners and designers to avoid the unintended negative consequences that result from some past spate irrigation improvement projects.

Of particular importance is the understanding of traditional water rights and operating and maintenance arrangements, how these are enforced and how water sharing, maintenance arrangements and the policing and enforcement of these arrangements would be affected by the project.

Projects should be planned with adequate time and resources to fully understand farmers' perceptions, the socio-economic circumstances and their risk avoidance strategies. Long-term programmes are required to allow stakeholders to adapt to changed technologies. Unfortunately, this recommendation often conflicts with the time bound programmes of typical investment projects.

Local capabilities, access to construction materials, indigenous skills, the availability of financial resources needed for farmers to carry out maintenance of any improved irrigation infrastructure must be carefully considered. In this regard it is important that the design and complexity of proposed infrastructure match the local capacity to operate.

Adapt design to arid zone context

Spate hydrology is characterized by a great variation in the size and frequency of floods, which directly influence the availability of water for agriculture and the design of diversion and distribution structures. Spate floods typically have very high peak discharges and short periods of flow. In designing spate irrigation improvement projects, the trade-offs between investment costs, maintenance costs and the level of service deserve more attention than for conventional irrigation. In particular, the specific characteristics of spate floods require a different approach towards risk management. Moreover, provision for re-building of parts of the system after major floods are often a more cost-effective option than designing more permanent structures.

The extreme characteristics of wadi hydrology make it difficult to determine the volumes of water that will be diverted to fields and hence the potential cropped areas. Reliance on farmers' experience is a better way to estimate potential than through classical crop-water requirement methods.

Wadis typically transport very high sediment loads (up to 10 percent in weight) which can be two or more orders of magnitude larger than those encountered in most perennial irrigation systems. Management of sedimentation is, therefore, a key factor in spate irrigation and must be given particular attention when designing spate projects. In particular, wherever possible, structures would have to be designed with stop logs on the main intake that can be raised in line with rising river bed levels and command areas.

Take a basin-wide approach to planning – Understand the water balance

Water is scarce in spate areas. A careful understanding of the water balance at the level of the river basin is necessary to avoid unintended negative consequences of spate interventions. Spate schemes should therefore be considered in the context of a succession of water uses in the basin and not as an isolated development. This is particularly the case in over-committed spate rivers, when even floodwater never reaches the sea. In such cases, all the water is already allocated to some use in the basin, and increased withdrawal at some point in the basin translates directly into reduced supply further downstream.

Spate irrigation modifies the different elements of the water balance in the basin. Typically, it offers opportunity for in situ groundwater recharge but, at the same time, reduces possible recharge downstream. In addition, most of the water diverted onto the land by spate irrigation is accounted for by evapotranspiration, and the proportion of groundwater recharge at the level of the river basin is therefore less. Only a water balance approach at the level of the river basin can help assess the impact of interventions on the overall productivity of water use.

One of the objectives of many projects is to increase the efficiency of agricultural water use. However, the scope for improving the efficiency of water diversion and distribution in traditional systems, which often already use a large proportion of the spate flows available for diversion may be limited. Improvements in water distribution and moisture conservation in the soil profile may be more beneficial than focussing solely on improving the efficiency of diversion from spate flows. In addition, water perceived as being 'lost' to a particular spate system may, in fact, recharge groundwater or be used downstream for useful, non-agricultural purposes such as riverine forest or rangeland.

Design with farmers

In all but the largest and most technically complex schemes farmers should drive the planning, design and execution of the rehabilitation and improvement works, as well as any amendment to existing water rights to facilitate the improvement of allocation and distribution of spate water. Engineers need to provide a range of technically and economically viable options and then assist farmers in selecting the most appropriate improvements for particular schemes.

Any improved water distribution system should ensure that farmers understand and agree with the implications of any implied changes to water distribution and, where new canals are needed, agree to provide the additional land required to construct the canals. This additional land will almost certainly be taken from previously irrigated land.

Farmers' involvement is particularly relevant in projects aiming to improve existing traditional spate systems (see Figure 11.1). They are generally the ones most able to identify the opportunities and possibilities for improvement in the water distribution, their limitations, the potential for extension, and the likelihood of success of any of the proposed interventions.

Adopt an incremental approach to spate improvement

Spate irrigation systems are, by their nature, dynamic and need to adapt to changing physical and socio-economic conditions. Physical changes in traditional spate-irrigation systems typically include changing wadi morphology, raising field levels, and destruction of irrigation infrastructure by large floods. In response, farmers have reconstructed damaged structures, and moved intakes upstream to regain command and capture base flows. Most traditional spate-irrigation systems have evolved and have been modified over time in reaction to these influences. Improvements were, in most cases, implemented by the spate irrigators themselves and were developed over long periods.

Changes in socio-economic conditions may happen within a relatively short time and affect the overall conditions in which spate irrigation takes place. They include changes in the local power structures that control access and distribution of water, access to new technologies that reduce labour requirements for maintenance or irrigation, easier access to roads, markets and labour opportunities, and policies that affect agricultural production and business.

FIGURE 11.1
Headwork discussions, Wadi Mai Ule, Eritrea

Whenever possible an incremental approach to spate irrigation improvement is a preferred option. It mimics farmers' approach and is flexible enough to accommodate the above-mentioned changes. Continuous support is preferred over a one-time project-type improvement to accompany these changes. The incremental approach is valid for infrastructure design as well as for operations and maintenance

Adapt design to operation needs

In large projects, the replacement of several independent traditional diversion structures by a single permanent diversion structure makes sense in engineering terms as it eliminates the need for farmers to rebuild diversions after floods and increases control over flood flows. However the experience has shown that concentrating diversion, by means of a permanent structure at one location, can result in conflict between upstream and downstream farmers related to the changes in distribution of, and access to, spate water. It is suggested that this approach should only be adopted when (a) downstream water users are not disadvantaged; (b) the sedimentation problems linked with permanent structures can be managed; and (c) appropriate sustainable levels of maintenance can be assured for technically advanced diversion structures.

In most cases low-cost, simple and maintenance-friendly technology should be used to improve existing traditional intakes. This might include providing access to bulldozers, constructing more durable diversions from local materials, and limiting the flows

entering the canals. Interventions should ensure that farmers are able to finance and have access to the skills and materials needed to carry out maintenance and repair works.
A rudimentary canal network with field-to-field irrigation is in place in many existing spate schemes. While improved canal networks, supplying water to controlled field outlets, can give better control and overcome some of the disadvantages of the field-to-field water system, changing the water distribution system will probably affect water rights. Any improved water distribution system should therefore:

- ensure that irrigation can be carried out quickly, in the short periods that spate flows occur. This requires canal and water control structures that have a much larger discharge capacity in relation to the area served than would be used normally in perennial irrigation systems;
- support the stability and manageability of the distribution network by creating structures that stabilize the bed of the flood channels, reinforce field-to-field overflow structures and ensure that gullies are quickly plugged; and
- ensure that water is spread over, and does not irretrievably disappear into the lowest parts of, the command area.

Ensure institutional arrangements for maintenance and operation

More than in any other type of irrigation, maintenance is key to the success of spate irrigation. The need for collective action is the basis of traditional spate irrigation practices, and the viability of spate systems is determined by the strength of the organizations involved in their construction and maintenance. Large, integrated systems can require relatively elaborate organizations, whereas small diversion structures can be operated more simply. The larger the system the more difficult it becomes to organize common maintenance activities, not least because some areas will always have a larger likelihood of receiving otherwise unpredictable flood supplies. While farmer management exists at some level in all spate systems, there are essentially three types of management arrangement (a) predominantly farmer-management; (b) where there is some involvement from local government or other external support; and (c) management by a specialized irrigation agency. In the latter, farmers may become passive recipients of water delivered to their turnouts.

For farmer-managed systems development projects should not attempt to unnecessarily formalize the agreements for maintenance. These have to be left as much as is possible to farmers. Projects should ensure that:

- there is clear leadership in farmer-managed systems, preferably by committees accountable to a wide constituency of land users and not to a limited interest group;
- there are clear and specific arrangements for maintenance. Maintenance arrangements must be able to cater for prolonged periods of crop failure;
- overhead and transaction costs are kept low and fixed tenure for official posts and positions are avoided;
- in large schemes sub-groups should be encouraged and strengthened so they can mobilize contributions to maintenance and enforce rules on water management at a local level; and
- extending the role of local organizations to crop management and, where appropriate, local groundwater regulation should be considered.

For agency-managed schemes:

- agency management is vulnerable if long-term routine financing cannot be guaranteed. Strengthening roles of both farmers and local government and reducing the role of specialist agencies should be promoted whenever possible. Public financial support is better directed at recovering from unusual damage and by investing in extension and farmer support rather than routine maintenance, which should generally be left to farmers;
- maintenance of the relatively complex infrastructure, found in some agency managed systems, has to remain a specialist activity. Involvement of the private sector, rather than employing a large full-time staff, in an irrigation agency may be appropriate;
- promotion of effective communication mechanisms is important to avoid a gap in perception and culture between agency staff and farmers; and
- farmer representatives elected from a wide constituency should play an important role in the management of agency schemes. Marginalization of farmer representatives, or undue influence by powerful interest groups, has to be resisted. Councils of user representatives, local government representatives and service organizations may be the most appropriate method of management.

Invest in soil moisture-management and improved agricultural practices

Interventions in spate systems have mostly concentrated upon improving the diversion of spate flows rather than improving the productivity of irrigation water. Improved soil management to maximize soil-moisture conservation may have an important impact on crop production. It should therefore be considered as an integral component of spate improvement projects in schemes where soil-moisture conservation is not currently practised.

Mulching, ploughing, pre-irrigation land preparation, breaking soil crust, the prevention of gullies and the adequate maintenance of field bunds can have a very large impact on crop production and water productivity. Small field-to-field structures, or the division of large fields into smaller more manageable areas, can sustain these improvements. Accurate estimates are difficult to get but better moisture management may multiply crop yield by a factor 1.5 to 3.

In particular, it is recommended that soil moisture conservation techniques be promoted in spate irrigation improvement projects where they are not currently practised. Field experiments in cooperation with farmers are a means of identifying and promoting the most appropriate measures.

Agricultural improvements are needed to raise water productivity. Generally, however, agricultural extension in spate-irrigated areas is poor and often lacks the resources and the specialist knowledge to meet the needs of spate farmers. Improving the quality and reach of extension services in spate-irrigated areas is obviously important, but is primarily a matter of regional or national priorities.

Research and training of extension workers and farmers could help increase the returns to marginal spate irrigators. A wide range of agronomic topics need research that is specific to spate-irrigation conditions and are described in this report. Possibly the most important of there are the development or dissemination of (a) higher yielding but drought-resistant varieties of spate-irrigated crops; and (b) improved water management and soil-moisture conservation practices. Other important subjects include the integration of indigenous technical knowledge with scientific knowledge, improvement of existing mixed/inter-cropping systems and the establishment of seed banks. Better grain storage to reduce post-harvest losses is often mentioned as being of major concern.

Protect fragile ecosystems

Ecosystems in arid and semi-arid river basins are generally precarious and vulnerable to externally-induced changes. Consideration should be given to the possible effects and impacts of the development of spate-irrigation systems on natural resources as well as water quality and quantity. Spate-irrigation systems are very much part of these natural resource systems and are themselves affected by changes in the land and water resources in the river basins.

Traditional spate irrigation is usually well adapted to local environmental conditions. As such, it is a more appropriate and cost-effective alternative to the development of perennial irrigation supplied from dams in arid areas where the rivers carry very high sediment loads. Interventions that mitigate the negative impacts of traditional spate practices, such as the unsustainable use of local trees and shrubs used to construct diversion structures, should be promoted. The use of natural vegetation, specifically planted for river training, provides an environmentally acceptable and lower cost option than the use of conventional hydraulic infrastructures.

RECOMMENDATIONS FOR SPECIFIC SCHEMES

Chapter 1 presented a range of characteristics that can be used to describe spate irrigation systems. Recommendations for basic types of schemes drawn from these descriptions on the basis of scheme size and management arrangements are made in this section.

Small schemes under farmer management using traditional diversion practices

These schemes are usually found on small wadis where the flood flows can, for the most part, be easily handled by farmers using relatively simple diversions. The main engineering requirement is to reduce the labour involved in re-building diversion spurs and bunds. One option is to provide farmers with mechanisms for accessing bulldozers to repair or construct diversions, provided effective arrangements for breaking of earthen spurs and bunds and water distribution, are in place. The support required to supply and maintain earth-moving plant, and provide trained operators, will be too large for small farmer groups and is best organized on a district or regional basis through local government, or with subsidies to allow the participation of the private sector.

Another option is to provide more durable, simple, un-gated diversions constructed from gabions, rubble masonry or concrete. Such structures need to be properly designed to resist scouring and overturning and should be simple for farmers to maintain using indigenous skills (this may rule out the use of gabions where they are not locally available at an acceptable cost to farmers). Flow-restricting structures and rejection spillways need to be included at the heads of canals when improved diversions are adopted, to prevent large uncontrolled flows damaging canals and downstream irrigation infrastructure.

New schemes in areas where spate irrigation is being introduced

Former rainfed farmers or herders will generally not have the skills and knowledge to manage spate flows on small schemes supplied from small tributary wadis. The development approaches described in the previous section may be applied in these situations but provision of a simple gated permanent structure will often be a better option when farmers do not have experience of using earthen bunds and deflectors to manage spate flows.

Medium/large schemes under farmer management using traditional diversion practices

These schemes are constructed in larger wadis carrying much larger flood flows. Typically they have numerous intakes ranging from simple deflectors at the upstream end of a wadi and diversion bunds in the lower reaches. The preferred option is to continue to treat these schemes as a series of independent small systems and to apply the options described above. This approach has the advantage that the farmer groups, and arrangements for water distribution and maintenance, remain unchanged. However, much larger floods generating larger forces and scouring action will be encountered in larger wadis. A higher level of engineering is needed to ensure that diversions are robust enough to withstand some damage and provide the flexibility needed to adjust to constant scouring and sedimentation.

A second option is to provide more permanent gated diversion structures, while minimizing the extent to which previously independent canals are consolidated to reduce the number of diversions required. Cost considerations will probably dictate the choice of the most convenient option, including the use of fuse plugs (breaching bunds) to reduce the cost of diversion weirs. However, in considering the cost of different options, the linkage between design, and the ease of operation and maintenance, must be valued carefully. In many cases, more expensive investment options, such us maintaining several independent small systems, may prove more productive and sustainable in the long run as they keep maintenance costs low and manageable by farmers.

Large schemes with improved infrastructure and agency management

Larger and technically complex systems are only feasible with an element of external management ranging from technical support provided by local irrigation or agriculture departments to full agency management. Where high development costs can be justified, quite complex permanent diversion and water control structures can be considered. In most cases they would not be recommended for reasons explained in details earlier. There is also the requirement to ensure the funding of adequate levels of maintenance in agency-managed schemes and to avoid inheriting potential technical problems with ill-designed spate diversion structures.

Schemes with access to sufficient shallow groundwater

Local geological conditions determine whether spate schemes have access to groundwater or not. Where possible, spate irrigation can be used to recharge groundwater, making possible the use of shallow groundwater for irrigation and other purposes. Access to shallow groundwater removes much of the insecurity associated with spate irrigation and allows production of cash crops with high crop-water requirements that cannot survive long periods between irrigations. In areas where there is sufficient shallow groundwater of suitable quality to make pump irrigation a feasible option, the adoption of an integrated approach, involving both spate irrigation and irrigation from shallow aquifers, is recommended.

The success of groundwater development in spate systems may, however, transform into a burden if exploitation of groundwater exceeds recharge. This is the case in coastal areas, where groundwater over-exploitation induces saline water intrusion and the destruction of the aquifers. Provision of communal wells, or the establishment of groundwater users associations, could be considered. In any case, properly conducted regional water balance studies are needed before shallow well irrigation is actively promoted in spate areas.

References and further reading

Abdulrazzak, M. 2000. *Water Management Experiences. In:* The Arabian Peninsula. Conference on Drought: Monitoring, Mitigation and Effects *(Siccità: Monitoraggio, Mitigazione, Effetti)*, Cagliari, 21–23 September 2000.

AFRICARE/ERITREA. 2001. Development Activity Program Proposal to the United States Agency for International Development for the AFRICARE/ERITREA Naro Irrigated Agriculture Project.

Ahmad, M. 1990. Keynote address. *In:* Rod-Kohi Agriculture. Agricultural Problems and Prospects Symposium. Pakistan Agricultural Research Council (PARC). Sponsored by BARD Project of PARC and Tipan of NWFP Agricultural University and Agricultural Research Institute, D I Khan. 27–29 November, 1989. pp. 3–10

Ahmad, S. 1999. *Land tenure and water rights in isolated spate irrigation systems in Balochistan, Pakistan.* WRRI/ICARDA.

Ahmad, S. 2000. *Indigenous water harvesting systems in Pakistan.* Islamabad, WRRI–NARC.

Ahmad, S. Rodriguez, A., Shah M.A. & Saddiq, M.N. 1998. *Land tenure and water rights in isolated spate irrigation systems in Balochistan, Pakistan.* WRRI/ICARDA.

Ahmed, A.G.M. & Teka, T. 1999. *Livelihoods in the Drylands of East Africa.* Horn of Africa Regional Workshop on Agricultural Policy, Resource Access and Human Nutrition. 3–5 November 1999, Imperial Hotel, Addis Ababa. Organisation for Social Science Research in Eastern and Southern Africa (OSSREA). 26 pp.

Al-Eryani, M. & Al-Amrani, M. 1998. *Social and organisational aspects of the operation and maintenance of spate irrigation systems in Yemen.* Background paper for PIM Seminar, Participatory Irrigation Management in Surface Irrigation Systems: Selected Studies. Hodeidah, 22–27 November 1998.

Al-Eryani, M. & Haddash, S. 1998. *Legal and organisational aspects and government regulations regarding water user associations (Case studies from Wadis Zabid, Rima, Abyan, and Tuban – Republic of Yemen).* Background Paper for PIM Seminar, Participatory Irrigation Management in Surface Irrigation Systems: Selected Studies. Hodeidah, 22–27 November 1998. World Bank Resident Mission, Ghayth Aquatech, Ltd.

Al-Eryani, M., Al-Hebshi, M. & Girgirah, A. 1998. *Estimation of the operation and maintenance expenditures for spate irrigation systems.* Background paper for PIM Seminar, Participatory Irrigation Management in Surface Irrigation Systems: Selected Studies. Hodeidah, 22–27 November 1998.

Al-Garoo, A.S. 1987. *Historic review of spate irrigation and its effect on agricultural development. In:* Spate Irrigation, Proceedings of the Sub-Regional Expert Consultation on Wadi Development for Agriculture in the Natural Yemen, Aden, December 1987. FAO/UNDP.

Al-Maktari, A. M. A. 1971. *Water rights and irrigation practices in Lahj:* A study of the application of customary and Shariah (Islamic) law in south-west Arabia. University of Cambridge Oriental Publications, No. 21, 202 pp., Cambridge University Press.

Al-Maktari, A.M.A. 1983. *Legal aspects of water and irrigation systems in the Arabian Peninsula.* Paper for Third International Symposium on the History of Arab Science, 10–14 December 1983, Kuwait.

Al-Shaybani, S.R. 2003. *Overview of non-modernised spate irrigation systems in Yemen.* Meta Meta, May 2003. Available at: http://www.spate-irrigation.org/pdf/tradspatesystemsinyemen-Part1.pdf

Amin, M. 1990. *Flood irrigation management in Balochistan. In:* Science for the People – Technology for Progress, Proceedings, National Seminar on Water Resources Development and its Management in Arid Areas, Quetta, 6–8 October, 1990. Vol. 2. Quetta. Pakistan Council of Research in Water Resources, Water Resources Research Centre. pp. 461–467.

Anderson, Ian McAllister. 2006. Eastern Lowlands Wadi Development Project, Wadi Laba and Wadi Mai Ule Irrigation Projects. Technical audit mission, March 2006.

Arcadis Euroconsult. 2002. *Water management in Wadi Tuban and Wadi Zabid.* Working paper 1, Irrigation Improvement Project, Sana'a.

Atkins & Partners. 1984. *Feasibility Study for Wadi Bana and Abyan Delta Development Project.* Vol. I Main report. 125 pp. Vol. II, Annexe A–Hydrology and water resources. 87 pp. Vol. III. Annex B, Engineering. 139 pp. WS Atkins & Partners in association with Binnie & Partners. Ministry of Agriculture and Agrarian Reform, People's Democratic Republic of Yemen.

Balochistan Minor Irrigation and Agricultural Development Project (BMIADP). 1994. *Agro-economic profile of Kharan District.* Quetta, WUA Liaison Section, February 1994. 25 pp.

Barrow, C.J. 1999. *Alternative irrigation: the promise of runoff agriculture.* London, Earthscan.

Bathurst, J.C. 1985. *Flow Resistance Estimation in Mountain Rivers*, Journal of Hydraulic Engineering. ASCE, Vol 111, pp. 625-641, April 1985.

Bhatti, S.A. & Khan, M.N.A. 1988. *Appropriate technology for management of flood-flows of DG Khan Hill Torrents. In:* Proceedings of National Seminar on Appropriate Irrigation Techniques for Water Scarcity Areas. Islamabad, ATDO.

Brendonck, L. & Williams, W.D. 2000. Biodiversity in wetlands of dry regions (dry lands). In: Gopal, B., W.J. Junk and J.A. Davis (eds). *Biodiversity in wetlands: assessment, function and conservation.* Vol 1. Leiden, The Netherlands, Buckhuys Publishers. pp. 181–194.

Brunner, U. & Haefner, H. 1986. The successful floodwater farming system of the Sabeans, Yemen Arab Republic. *Applied Geography,* 6: 77–86.

Camacho, R.F. 1987. *Traditional spate irrigation and wadi development schemes. In:* Spate irrigation: proceedings of the Subregional Expert Consultation on Wadi Development for Agriculture in the Natural Yemen. 6–10 December, 1987. Aden, PDR Yemen. UNDP/FAO. pp. 60–72.

Camacho, R.F. 1992. *Balochistan minor irrigation and agricultural development Project.* Flood Irrigation. Phase II Preparation Studies. Mission Report. 14 May to 14 June, 1992. Halcrow-ULG Ltd, Euroconsult, technical assistance team, Quetta, Balochistan.

Camacho, R.F. 2000. *Spate irrigation in Konso, Ethiopia: review of methods for improvement of spate irrigation.* Konso Development Association and Farm Africa.

Cleveringa, R., Nepveu de Villemarceau, A. & Adeeb, Ali M. 2006. *Local governance to secure access to land and water in the lower Gash watershed.* Rome. IFAD.

Daniel, T., Tesfa-alem, G., Woldemariam G. & Alemseged, M., *Monitoring and evaluation of spate irrigation in Tigray Mekelle*. Tigray Water Resources Development Commission.

Department for International Development (DFID). 1999. *Sustainable Livelihoods Guidance Sheets.* Available at: http://www.livelihoods.org/info/info_guidancesheets.html#6

DHV Consulting Engineers. 1979. *Wadi Rima irrigation development: feasibility study,* Vol. 1 main report.

DHV Consulting Engineers. 1988. *Tihama basin water resources study.* Main report. Yemen Arab Republic. Ministry of Agriculture and Fisheries Resources. Tihama Development Authority. 95 pp.

Drylands Co-ordination Group (DCG). 2002. *Sustainable livelihoods of farmers and pastoralists in Eritrea.* Proceedings from a workshop organized by DCG Eritrea in National Confederation of Eritrean Workers Conference Hall, Asmara, November 28–29, 2002. DCG Proceedings No. 8. 120 pp.

El-Hassan, B.A. 1999. *Environmental protection studies and activities in the Tihama Plains of Yemen.* Paper presented to the Workshop to Review the NAPCD (National Action Plan to Combat Desertification), Sana'a, 30 May – 2 June, 1999.

Enge, K.I. & Scott, W. 1989. *The keepers of water and earth. Mexican rural social organization and irrigation.* Austin, Texas, University of Texas Press.

Euroconsult-Mott MacDonald & MetaMeta. 2008. *Improving the Tihama Development Organisation.* Internal Report Technical Assistance to the Food Security Programme.

FAO. 1981. *Arid zone hydrology for agricultural development.* FAO Irrigation and Drainage Paper 37. Rome. 271 pp.

FAO. 1994. *Eritrea: agricultural sector review and project identification.* Vol. 1, main report. Report prepared by FAO for the Government of Eritrea. Rome.

FAO. 2000. *Special report: FAO/WFP crop and food supply assessment mission to Sudan.* Rome: FAO. Available at: www.fao.org/docrep/004/x4278e/x4278e00.htm

FAO. 2007. *Survey on modernization of irrigation schemes*, Available at: www.fao.org/ag/agL/AGLW/watermanagement/modernis.stm#background

FAO. 2010. Proceedings of the FAO Expert consultation on spate irrigation, Cairo, April 2008.

FAO–AQUASTAT. 2010. FAO's information system on water and agriculture. Available at: http://www.fao.org/nr/water/aquastat/main/index.stm

FAO/UNDP. 1987. *Spate irrigation.* Proceedings of the subregional expert consultation on wadi development for agriculture in the Natural Yemen, 6–10 December, 1987. Aden, PDR Yemen, New York and Rome.

Farm Africa. 2003. *Spate irrigation in Konso Special Wadera.*

Farquharson F.A.K., Meigh J. R. & Sutcliffe J. V. 1992. *Regional flood frequency analysis in arid and semi-arid areas*. Journal of Hydrology, 138, (3-4): 487-501. Amsterdam, Elsevier Science Publishers BV.

Gebre, M. 2001. *A design report of Ondoloko spate irrigation project.* Farm Africa. Konso. SNNPRS (Southern Nations, Nationalities and People's Regional State). 29 pp.

Gilani, P.M.S. 1990. *Farmers' experiences in Rod-Kohi area. In:* Rod-Kohi Agriculture. Agricultural Problems and prospects symposium. Pakistan Agricultural Research Council (PARC). Sponsored by BARD Project of Pakistan Agricultural Research Council and Tipan Project of NWFP Agricultural University at Agricultural Research Institute, DI Khan, 27–29 November, 1989. pp. 127–130.

Girgirah, A.A., Maktari, M.S., Sattar, H.A., Mohammed, M.F., Abbas, H.H. & Shoubihi, H.M. 1987. *Wadi development for agriculture in PDR Yemen. In:* Spate irrigation: proceedings of the Subregional Expert Consultation on Wadi Development for Agriculture in the Natural Yemen, 6–10 December, 1987. Aden, PDR Yemen. UNDP/FAO. pp. 9–25.

Goldsworthy, T.J. 1975. *Agricultural report on the Montane Plains and Wadi Rima project, Yemen Arab Republic.* Project Record No.5. Miscellaneous Report No. 204. Surrey, UK, Land Resources Division. 48 pp.

Ground Water Consult. 1991. *Balochistan: flood water irrigation schemes.* Report prepared for the Royal Netherlands Embassy, Islamabad.

Hadera. M. 2001. *Soil and water management in spate irrigation systems in Eritrea.* Tropical Resource Management Papers 36, Wageningen, the Netherlands.

Hadera. M. & Graaff, J.de, 2000. Participatory rural appraisal of spate irrigation system in eastern Eritrea. *Agriculture and Human Value*s 17: 359–370.

Hag Nur, A. & Abdi Mah, H. 1987. *Spate irrigation in Somalia. In:* Spate irrigation, proceedings of the Sub-regional Expert Consultation on Wadi Development for Agriculture in the Natural Yemen, Aden, December 1987. FAO/UNDP.

Haile, A., Selassie, D.G., Zereyacob, B. & Abraham, B. 2003. *On-farm storage studies in Eritrea.* Drylands Co-ordination Group. (DCG) Report No. 28, 49 pp.

Haile, A.M., Schultz, B. & Depeweg, H. 2003. Experienced eyes versus accurate measurement: water sharing in the spate irrigation systems in the Sheeb, Eritrea. Available at: http://afeid.montpellier.cemagref.fr/Mpl2003/Conf/Haile.pdf

Haile, B. 1999. *Construction of spate diversion structures.* Wageningen, Agricultural University. (MSc thesis)

Haile, G. B. & van Steenbergen, F. 2006. Agricultural water management in ephemeral rivers: Community Management in Spate Irrigation in Eritrea. *African Water Journal,* 1(1): 54–71.

Hailu, M. & Merga, S.N. 2001. *Workshop on the experience of water harvesting in the drylands of Ethiopia: principles and practices.* 28–30 December, 2001, Mekelle, Ethiopia. Drylands Co-ordination Group Report No. 19. 125 pp.

Halcrow & Partners Ltd. 1993a. Flood Irrigation in Balochistan. Internal Memo; Quetta, BMIADP.

Halcrow & Partners Ltd. 1993b. *Phase II Preparation Studies, flood irrigation schemes, Chandia, feasibility study 1. Vol. 1, main report.* Government of Balochistan. Balochistan Minor Irrigation and Agricultural Development Project. Sir William Halcrow & Partners Ltd, in association with ULG Consultants Ltd, Euroconsult and NESPAK. pp. 69–76.

Halcrow & Partners Ltd. 1993c. *Barag*, Feasibility Study 2, Vol. 1, main report. Quetta, BMIADP.

Halcrow & Partners Ltd. 1993d. *Marufzai*, feasibility study 3, Vol. 1 main report. Quetta, BMIADP.

Halcrow & Partners Ltd. 1993e. *Phase II preparation studies, flood irrigation schemes. Nal Dat feasibility study 4.* Vol. 1– main report. Government of Balochistan. Balochistan Minor Irrigation and Agricultural Development Project. Sir William Halcrow & Partners Ltd, in association with ULG Consultants Ltd, Euroconsult and NESPAK. pp. 69–70, 92 pp.

Halcrow & Partners Ltd. 1993f. *Mouza Yo Bund, Field Visit Report.* Quetta, BMIADP.

Halcrow & Partners Ltd. 1994. Korakan Flood Irrigation Study. Internal Memo. Quetta, BMIADP.

Halcrow & Partners Ltd. 1997. *Working paper 3 – Hydrology, Eastern Lowlands Wadi Development Project,* Engineering feasibility report, Ministry of Agriculture, Asmara.

Halcrow & Partners Ltd. 1997a. *Strategy for on farmer participation and formation of farm organizations.* Asmara, ELWDP.

Halcrow & Partners Ltd. 1997b. *Engineering feasibility report*. Vol. 3 – working paper. 3 – Hydrology. Eastern Lowlands Wadi Development Project. Ministry of Agriculture, Asmara. Sir William Halcrow & Partners Ltd & Geoscience plc Joint Venture. R 16193. July 1997. 30 pp.

Halcrow & Partners Ltd. 1998. *Toiwar flood irrigation scheme, feasibility report* F 05. Government of Balochistan. Balochistan Community Irrigation and Agriculture Project. Sir William Halcrow & Partners Ltd, in association with ULG Consultants Ltd, Euroconsult and NESPAK. pp. 29–45.

Halcrow & Partners Ltd, Euroconsult, NESPAK & Techno Consult. 2002a. *BCIAP design manual. Annex 1:* monthly rainfall data. Government of Balochistan. Balochistan Community Irrigation and Agriculture Project. Technical Assistance Team, Quetta, Balochistan. April 2002.

Halcrow & Partners Ltd, Euroconsult, NESPAK, Techno Consult. 2002b. *BCIAP Design Manual. Part 2*: Flood estimation. Government of Balochistan. Balochistan Community Irrigation and Agriculture Project. Halcrow, Euroconsult, NESPAK, Techno Consult. Techncial Assistance Team, Quetta, Balochistan. March 2002. 37 pp.

Hehmeyer, I. 2000. *The spirit of cooperation in Yemeni agricultural practices – successful cases from the past, and their applicability for the present.* Proceedings of conference: The Place of Ancient Agricultural Practices and Techniques in Yemen Today: Problems and Perspectives. Sana'a, Yemen, 18–20 June, 2000. Available at: http://www.aiys.org/webdate/pelheh.html

Heiler, T.D. & Brown, W.A.N. 1989. *The implications of Rod-Kohi to Stage III of the Chasma Right Bank Irrigation Project. In:* Rod-Kohi Agriculture. Agricultural Problems and Prospects Symposium. Pakistan Agricultural Research Council (PARC). Sponsored by BARD Project of PARC and Tipan Project of NWFP Agricultural University at Agricultural Research Institute, DI Khan. 27–29 November, 1989. pp. 46–51.

Hobieshan, A.S. 2004. The customs followed for water utilization rights (Mimeo. IIP).

Hodge, A. 2001. The dams that drank a river. *The Australian*, 31 March 2001.

HR Wallingford. 1983. *Wadi Mawr.* Phase II, model study. Report EX 1148. 29 pp.

Hussain, K. 2000. *Chasma right bank irrigation project (CRBIP):* a survey report. Islamabad, Sungi Development Foundation and Damaan Development Organization.

Hussain, K. 2002. *Gomal Zam dam project: a survey report.* Islamabad, Action Aid Pakistan and Sungi Development Foundation.

International Centre for Agricultural Research in the Dry Areas (ICARDA). 1998. Spate Irrigation Systems of Balochistan, Pakistan. *ICARDA Annual Report 1998*. Available at: http://www.icarda.cgiar.org/Publications/AnnualReport/98/AnPage34.HTML

International Commission on Irrigation and Drainage (ICID). 2010. *ICID multilingual technical dictionary on irrigation and drainage.* Revised edition, New Delhi.

International Fund for Agricultural Development (IFAD). 1992. Yemen – Country Portfolio Evaluation, CPE92 CESYE92E. Rome.

International Fund for Agricultural Development (IFAD). 1995. *Appraisals report on Eastern Lowland Wadi Development Project (ELWDP).* Ministry of Agriculture, Asmara and IFAD, Rome. 52 pp.

International Fund for Agricultural Development (IFAD). 2003. *The Republic of Yemen: Tihama Environmental Protection Project.* Interim evaluation report No. 1360 YE. Rome. 99 pp.

International Hydrological Programme (IHP). 1996. *Proceedings of the UNESCO/NWRC/ACSAD Workshops on Wadi Hydrology and Groundwater Protection.* Cairo, 3–6 June 1996. Eds. Mourits, L.J.M., Salih, A.M.A. and Sherif, M.M. IHP-V. Technical Documents in Hydrology, No.1. UNESCO, Cairo Office. 1–65 pp.

Iqbal, M. 1990. *Forestry in Rod-Kohi tract of DI Khan. In:* Rod-Kohi agriculture. Agricultural Problems and Prospects Symposium. Pakistan Agricultural Research Council (PARC). Sponsored by BARD project of PARC and Tipan of NWFP Agricultural University at Agricultural Research Institute, DI Khan. 27–29 November, 1989. pp. 146–153.

Irrigation Improvement Programme (IIP). 2002. *Socioeconomic household baseline survey and focus group discussions in Wadi Zabid and Wadi Tuban.*

Jacobson, P., Kathryn J. & Mar, S. 1995. *Ephemeral rivers and their catchments: sustaining people and development in Western Namibia.* Windhoek, Desert Research Foundation of Namibia.

Jamal, K.M. & Muhammad, I. M. 2004. *Assessment of water availability and evaluation of traditional rod-kohi irrigation system in DI Khan.* Peshawar, NWFP Agricultural University/Intercooperation.

Kahlown, M.A. & Hamilton, J.R. 1996. Sailaba irrigation practices and prospects. *In: Arid Soil Research and Rehabilitation,* 10:179–191.

Kahsaye, W. 2002. *The cultural ecology of pastoralism in Eritrea – A geographical inquiry.* Louisiana State University. (PhD thesis)

Khan, A.B. 1979. *National Seminar on Land and Water Resources Development of Barani Areas.* Organized by Centre of Excellence in Water Resources Engineering. Sponsored by Pakistan Science Foundation, University Grants Commission, Pakistan Agriculture Research Council, Agency for Barani Areas Development (ABAD), July 1979. pp. 80–87.

Khan, A.B. 1990. *Research problems and needs of Rod-Kohi agriculture in DI Khan. In:* Rod-Kohi Agriculture. Agricultural Problems and Prospects Symposium. Pakistan Agricultural Research Council (PARC). Sponsored by BARD Project of PARC and Tipan of NWFP Agricultural University at Agricultural Research Institute, DI Khan, 27–29 November, 1989. pp. 72–75.

Khan, B.R. & Akbar G. 1990. *Sailaba (Rod-Kohi) agriculture in Baluchistan. In:* Rod-Kohi Agriculture: Problems and Prospects Symposium. Pakistan Agricultural Research Council (PARC). Sponsored by BARD project of PARC & Tipan of NWFP Agricultural University at Agricultural Research Institute, DI Khan, 27–29 November, 1989. pp. 85–94.

Khan, G.S., & Rafiq, M. 1990. *Soils of the Rod-Kohi Piedmont Plains of the Sulaiman Range. In:* Rod-Kohi Agriculture: Problems and prospects symposium. Pakistan Agricultural Research Council (PARC). Sponsored by BARD project of PARC and Tipan project of NWFP Agricultural University at Agricultural Research Institute, DI Khan. 27–29 November, 1989. pp. 52–59.

Khan, K.B. 1979. *The role of hill torrents in Barani areas in Pakistan.* National seminar on Land and Water Resources Development of Barani Areas. Organized by Centre of Excellence in Water Resources Engineering. Sponsored by the Pakistan Science Foundation, University Grants Commission, Pakistan Agriculture Research Council, Agency for Barani Areas Development (ABAD). July 1979. pp. 54–67.

Khan, M. 1990. *BARD experiences in Rod-Kohi agriculture. In:* Rod-Kohi agriculture. Agricultural Problems and Prospects Symposium. Pakistan Agricultural Research Council (PARC). Sponsored by BARD Project of PARC and Tipan Project of NWFP Agricultural University at Agricultural Research Institute, DI Khan, 27–29 November, 1989. pp.98–114.

Kit. 2002. *Economic opportunities in Shabwah: improving people's livelihoods by sustainable economic development; In:* Poverty, livelihoods, risks and coping strategies in spate irrigation systems. Ataq, Republic of Yemen, Small Businesses Development Programme.

Kohler, S. 1996. The demands and limitations of sustainable water use in arid regions: a discussion of sustainable development taking the Wadi Markhah (Republic of Yemen) as an example. *In: Applied Geography and development,* 47: 25–36.

Kohler, S. 1999. *Institutionen in der Bewasserungs-Landwirtschaft im Jemen.* Wiesbaden Jemen-Studies Band 13.

Komex. 2002. Groundwater assessment of Wadi Tuban. Sana'a, NWRA.

Kowsar, S.A. 1998. *Aquifer management: a new approach to soil and water conservation in the deserts of Iran. In:* New technologies to combat desertification. Proceedings of the International Workshop held in Tehran, Iran. 12–15 October 1998.

Kowsar, S.A. 2005. Abkhandari (Aquifer Management): a green path to the sustainable development of marginal lands. *Journal of Mountain Science*, 2, 3. 233–243.

Lackner, H. & Vincent, L. 1998. *Participatory irrigation management in spate irrigation in Yemen (case studies from Wadis Zabid, Rima, Abyan, and Tuban – Republic of Yemen).* A report for the Economic Development Institute of the World Bank. Wageningen Agricultural University, The Netherlands, Irrigation and Water Engineering Group. 24 pp.

Lambrick, H.T. 1986. *Sind: A general introduction.* Third printing. Hyderabad, Sindh Adabai Board.

Lawrence P. 1982. *Performance of gabion bed stabilizers in the Wadi Rima, Yemen Arab Republic.* Hydraulics Research, Wallingford. Report No. OD 49. In collaboration with the Tihama Development Authority, Ministry of Agriculture, Yemen Arab Republic. 19 pp.

Lawrence, P. 1983. *Wadi Rima – Hydraulic model investigation.* Hydraulics Research, Wallingford. Report No. OD 54. 23 pp.

Lawrence, P. 1986. *Wadi Zabid Diversion structures – field performance measurements.* Hydraulics Research, Wallingford. Report OD 73. 31 pp.

Lawrence, P., HR Wallingford, Halcrow & Partners Ltd in association with ULG Consultants, Euroconsult & NESPAK. 1993. *Flood irrigation. Sediment control and transport. Preliminary design Guide.* Phase II Preparation Studies, Balochistan Minor Irrigation and Agricultural Development Project. Quetta, Government of Balochistan. Technical Assistance Team, Balochistan, March 1993. 25 pp.

Lawrence, P. 2009. *Managing sedimentation in spate irrigation schemes.* Lecture note, short course on spate irrigation and water management under water scarcity, Delft, The Netherlands, UNESCO-IHE Institute for Water Education.

Mac Anderson, I. 2006. *Eastern lowland wadi development project.* Technical audit mission, report to IFAD/ World Bank.

MacDonald (Ian MacDonald and Associates Ltd). 1987a. *Diagnostic study of farming systems in Baluchistan: Kachhi District.* Baluchistan Agricultural Extension and Adaptive Research Project.

MacDonald (Ian MacDonald & Associates Ltd). 1987b. *Diagnostic study of farming systems in Baluchistan: Lasbela District.* Baluchistan Agricultural Extension and Adaptive Research Project.

Mace, A.S. 1997. *Sediment transport measurement in Wadi Laba, State of Eritrea.* Research Report 23. University of Newcastle-upon-Tyne, Water Resource Systems Research Unit, Department of Civil Engineering. (Thesis submitted in partial fulfilment of the requirements for MSc in Water Resource Systems Engineering). 76 pp.

Mahmood, K., Sanmuganathan, K. & Oosterman, J. 1985. *Wadi Mawr Project. Report on design review and recommendations.* Yemen Arab Republic, Tihama Development Authority. 41 pp.

Makin, M.J. (ed.). 1977a. *Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resources survey. Irrigation and agricultural development in Wadi Rima,* Vol. 1. Land Resources Division Project Team. Project Report 16. Land Resources Division, UK. 202 pp.

Makin, M.J. (ed.). 1977b. *Yemen Arab Republic Montane Plains and Wadi Rima Project: a land and water resources survey. Irrigation and agricultural development in Wadi Rima,* Vol. 2. Land Resources Division Project Team. Project Report 16. Land Resources Division, UK. 202 pp.

McCoriston, J. 2000. *Ancient agricultural practices in Hadramawt: new insights from the RASA Project.* Proceedings of conference: The Place of Ancient Agricultural Practices and Techniques in Yemen Today: Problems and Perspectives. Sana'a, Yemen. 18–20 June, 2000. Available at: http://www.aiys.org/webdate/peljoy.html

Mehari, A. 2007. *A tradition in transition: indigenous spate irrigation systems and water management reform,* ISBN 10 0-415-43947-7, The Netherlands, Taylor and Francis. 212 pp.

Mehari, A., Schultz, B. & Depeweg, H. 2003. *Water sharing and conflicts in the Wadi Laba spate irrigation system, Eritrea.* Sponsored by the Netherlands Government within the NUFFIC-MHO programme: cooperation between the University of Asmara, Eritrea and the Wageningen University, ref. MHO/UoA/WU, Agricultural Science II Project No. ERI/624A and ERI/625B.

Mehari, A., Schultz, B. & Depeweg, H. 2005a. Where indigenous water management practices overcome failures of structures. *Irrigation and Drainage*, 54(1): 1–14.

Mehari, A., Schultz, B., Depeweg, H., 2005b. Hydraulic performance evaluation of the spate irrigation systems in Eritrea. *Irrigation and Drainage,* 54(4), 1–18.

Mehari, A., Schultz, B., Depeweg, H. & De Laat, P.J.M. 2008. Modelling soil moisture and assessing its impact on water sharing and crop yield for the Wadi Laba spate irrigation system, Eritrea. *Irrigation and Drainage*, 57(1): 1–16.

Mehari, A., van Steenbergen, F. & Schultz, B. 2005. Water rules and rights and management in spate irrigation systems. In: B. van Koppen, J. Buttersworth and I.J. Juma (eds), *African water laws: plural legislative frameworks for rural water management in Africa: proceedings of workshop*, Johannesburg 26–28 January 2005. Pretoria, IWMI. pp. 23-1–15.

Mehari, A., van Steenbergen, F. & Schultz, B. 2007. Water rights and rules and management in spate irrigation systems in Eritrea, Yemen and Pakistan. In: Van Koppen, B., Giordano, M. and Butterworth, J. (eds). *Community-based water law and water resource management reform in developing countries. Comprehensive Assessment of Water Management in Agriculture Series 5.*, Wallingford, UK, CAB International.

Michael, Y.G. 2000a. *Small-scale irrigation and food security issues: the case of Konso special woreda (Southern Nations, Nationalities and People's Region).* 28 pp.

Michael, Y.G. 2000b. *The role of agricultural extension in food security in vulnerable areas: The case of Lemo and Konso Woredas (Southern Nations, Nationalities and People's Region).* September 2000, 41 pp.

Molden, D. (ed). 2007. *Water for food, water for life. A Comprehensive assessment of water management in agriculture.* New York and Colombo, Earthscan and IWMI.

Morton, J. & van Hoeflaken, H. (1994). *Some findings of a survey of flood irrigation schemes in Balochistan, Pakistan.* IMN Network Paper 31. London: ODI, 1–9.

Moustafa, A.T.A., El-Meligy, A.A. & Allam, M.A.A. 1987. *Spate irrigation in Egypt. In:* Spate Irrigation: proceedings of the Sub-Regional Expert Consultation on Wadi Development for Agriculture in the Natural Yemen, Aden, December 1987. FAO/UNDP.

Mu'Allem, A.S. 1987. *Crop production under spate irrigation in coastal areas of PDRY. In:* Proceedings of the Sub-Regional Expert Consultation on Wadi Development for Agriculture in the Natural Yemen, 6–10 December 1987 Aden, PDR Yemen. UNDP/FAO. pp. 51–57.

Munir, M. & Kahlown, M.A. 1989. *Sailaba irigation in Baluchistan: benchmark study.* Lahore, WAPDA Planning Directorate (south).

National Engineering Services Pakistan (Pvt) Ltd. 1998. *Master feasibility studies for flood management of hill torrents of Pakistan.* Lahore, NESPAK.

National Engineering Services Pakistan (Pvt) Ltd. 1998. *Master feasibility studies for flood management of hill torrents of Pakistan, main report.* Islamic Republic of Pakistan, Federal Flood Commission, Ministry of Water and Power.

Nawaz, K. 2002. *Spate irrigation systems in Pakistan – An alternative to present crises* (draft). Pakistan, Pakistan Agricultural Research Council (PARC).

Nawaz, K., 2003. *Spate irrigation in Dera Khazi Khan, Pakistan.* Available at: http://www.spate-irrigation.org

Nawaz, K. & Qazi, M.U. 2002. *Spate irrigation in Pakistan: problems and prospects.* Available at: http://www.spate-irrigation.org/librar/spate_pakistan.htm

Nejabat, M. 1999. *Improving environmental characteristics in a wide area around a flood water spreading system: a case study.* Ninth International Rainwater Catchment Systems Conference: Rainwater Catchment: An Answer to the Water Scarcity of the Next Millennium. Section 4: Technology of Rainwater Catchment Systems, Paper 4.20, Petrolina, Brazil, July 1999, International Rainwater Catchment Systems Association.

Niemeijer, D. 1993. *Indigenous runoff farming systems in a changing environment: the case of Kassala's border area, Sudan.* Landscape and Environmental Research Group, University of Amsterdam and Department of Irrigation and Soil and Water Conservation, Wageningen Agricultural University. 210 pp.

Nizami, M.I. & Akhtar, M.E. (Dr). 1990. *Soil crusting and management in Rod-Kohi areas of Pakistan. In:* Rod-Kohi Agriculture. Agricultural Problems and Prospects Symposium. Pakistan Agricultural Research Council (PARC). Sponsored by BARD Project of PARC and Tipan of NWFP Agricultural University at Agricultural Research Institute, DI Khan, 27–29 November, 1989. pp.195–199.

Ogba-Michael, B. 2004. *The State of Eritrea: agronomy in spate-irrigated areas of Eritrea.* Ministry of Agriculture, Department of Regulatory Services, Plant Health Division. Ministry of Agriculture, P.O. Box 1048, Asmara, Eritrea.

Oosterman, J. 1987. *Diversion structures and protection works.* Rome/New York, FAO/UNDP.

Oudra, Ismail, 2008. *Spate irrigation in Morocco: country profile.* Paper prepared for FAO Expert Meeting on Spate Irrigation, Cairo 7–10 April 2008.

Oweis, T., Orinz, D. & Hachum, A. 2001. *Water harvesting: indigenous knowledge for the future of the drier environments.* Aleppo, ICARDA.

Pakistan Agricultural Research Council (PARC). 1990. *Rod-Kohi Agriculture. In:* Problems and Prospects Symposium. Sponsored by BARD Project of Pakistan Agricultural Research Council and Tipan Project of NWFP Agricultural University at Agricultural Research Institute, D I Khan, 27– 9 November, 1989. PARC, 1990. 218 pp.

Pakistan Water and Power Development Authority. 1976. *Hill torrents in Pakistan.* Lahore, Planning and Investigation Division, P&I Publication No. 1999.

Pratt, D.J. 1977. *Yemen Arab Republic – Montane Plains and Wadi Rima Project: a land and water resources survey. An investment and development plan for Wadi Rima.* Ministry of Overseas Development, project report 17. YAR-01-30/Rep-17/77. Surrey, UK, Land Resources Division.167 pp.

Qadir, A. & van Steenbergen, F. 1993. Visit Report.: Mouzo Yo Bund FIS Scheme (Phase II). 18–20 January 1993.

Queensland Government. 2000. *Draft water allocation and management plan (Condamine-Balonne Basin).* Department of Natural Resources.

Rahbar, G.R. & Kowsar, S.A. 1999. *An assessment of the damage sustained by the Gareh Bygone Plain artificial recharge of groundwater system in the deluge of 1995.* Ninth International Rainwater Catchment Systems Conference, Rainwater Catchment: An Answer to the Water Scarcity of the Next Millennium, July 1999. Section 4: Technology of Rainwater Catchment Systems, Paper 4.20. Petrolina, Brazil, International Rainwater Catchment Systems Association.

Rahman Shahin, F.A. 1990. *Wadi Mawr Project. Short study on water regulation and distribution* (draft report). Government of the Yemen Arab Republic, Ministry of Agriculture and Fisheries Resources, Tihama Development Authority. MPWWR, Egypt.

Randall, J.S. & Sharon, A. 2005. *Soils: Genesis and Geomorphology.* UK, Cambridge University, Press, ISBN: 0521812011. 832 pp.

Rehan, K. 2002. *Hydrodynamic modelling and water management plan for the Toiwar flood irrigation scheme.* Delft, International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE). 104 pp. (MSc thesis).

Roux & Thouillot. 2006. *Livestock performances depending more on investment level than on herd management.*, Ecole Supérieure d'Agriculture de Purapn (ESAP) and, Centre National d'Etudes Agronomiques en Régions Chaudes (CNEARC). 219 pp.

Salameh, N.H. 1995. *Šarià und Gewohnhietsrecht in Zabid: dargestellt an ausgewähtlen Fällen zum Wasserrecht.* Mainz, Johannes Gutenberg-Universität. (MA thesis).

Salman, M., Faurès, J.M. & Casarotto, C. (unpublished). *Investment costs in irrigation: a statistical analysis of a global project database.* Internal Document. FAO.

Sánchez, R.M. 2001. *De la autonomía a la subordinación:* riego, organización social Y administración de recursos hidráulicos en la cuenca del Río Laja, Guanajuato, 1568–1917, El Colegio de México. (Tesis de Doctorado en Historia)

Scheitz, E.L. 1987. *Certain aspects and problems of wadi development. In:* Spate irrigation, Proceedings of the Sub-Regional Expert Consultation on Wadi Development for Agriculture in the Natural Yemen, Aden, December 1987. FAO/UNDP.

Schellart, H. 2003. *Design of protection and consolidation works for the Barquqa irrigation scheme (Tihama V), a food security project in Yemen.* Sana'a, Euronet/ Commission of the European Union.

Scholte, P., al-Khuleidi, A.W. & Kessler, J.J. 1991. *The vegetation of the Republic of Yemen (western part).* Dhamar: Environmental Protection Council/Agricultural Research Authority/DHV Consultants.

SCWMRI (Soil Conservation and Watershed Management Research Institute). 2003. *Floodwater utilization (Abkhandary): a way to achieve groundwater recharge, drought effects mitigation and sustainable agricultural development.* Iran, Agricultural Research and Education Organization.

Serjeant, R.B. 1980. *Report on land and water rights with other relevant topics in the Montane Plains and Wadi Rima (MPWR) Project, Yemen Arab Republic.* Project Record 3. Yar-01-6/Rec-3/74.

Shah, S.H. 1990. *Cropping patterns in Rod-Kohi agriculture in DI Khan. In:* Rod-Kohi agriculture. Agricultural problems and prospects symposium. Pakistan Agricultural Research Council (PARC). Sponsored by BARD Project of PARC and Tipan Project of NWFP Agricultural University at Agricultural Research Institute, DI Khan, 27–29 November, 1989. pp.115–121.

Shahin, F.A.R. 1990. *Wadi Mawr Project – Short study on water regulation and distribution* (draft report).

Sheikh, M.I., Shah, B.H. & Aleem, A. 1984. Effect of rainwater harvesting methods on the establishment of tree species. *Forest Ecology and Management,* Vol. 8, (3–4): 257–26, Amsterdam, Elsevier Science Publishers B.V. pp.3.

Sivanappan, R.K. 2001. Technology: enhancing agricultural production, boosting yields in semi-arid regions. *In:* Eds. Agarwal, A., Narain, S. & Khurana, I. *Making water everybody's business–practice and policy of water harvesting*. pp. 276–281, ISBN-81-86906-28-2, Centre for Science and Environment.

Tesfai, M. 2001. *Soil and water management in spate irrigation systems in Eritrea.* Tropical Resource Management Papers, No. 36. pp.1–10, 45–95, 113–184. Wageningen University and Research Centre.

Tesfai, M. & de Graaff, J. 2001. Participatory rural appraisal of spate irrigation systems in eastern Eritrea. *In: Soil and water management in spate irrigation systems in Eritrea.* Tropical Resource Management Paper, No. 36. pp. 25–44. Wageningen University and Research Centre.

Tesfai, M. & Sterk, G. 2001. Sedimentation rate on spate irrigated fields. *In: Soil and water management in spate irrigation systems in Eritrea.* pp. 97–111. Tropical Resource Management Papers, No. 36. Wageningen University and Research Centre.

Tesfai, M, & Stroosnijder, L. 2001. The Eritrean spate irrigation system. *In: Soil and water management in spate irrigation systems in Eritrea.* Tropical Resource Management Papers, No. 36. pp.11–24. Wageningen University and Research Centre.

Thoms, M., Quinn, G., Butcher, R., Phillips, B., Wilson, G., Borck, M. & Gawne, B. 2002. *Scoping study for the Narran Lakes and lower Balonne floodplain management study.* CRCFE technical report 3/2002, Canberra, CRC for Freshwater Ecology.

Tihama Development Authority. 1987. *Wadi development for agriculture in Yemen Arab Republic. In:* Spate irrigation, proceedings of the sub-regional expert consultation on wadi development for agriculture in the natural Yemen. Aden, December 1987. FAO/UNDP.

Tipton and Kalmbach. 1978. *Development of Wadi Mawr Tihama Development Authority, Yemen Arab Republic.* Tihama Development Project. Denver, Colorado, USA and Hodeida, Yemen Arab Republic. 169 pp.

Tipton & Kalmbach. 1980. *Wadi Zabid agricultural project. Operation and maintenance manual.* Tihama Development Authority, Yemen Arab Republic. Denver, Colorado, USA and Hodeida, Tipton and Kalmbach, Inc., Engineers.134 pp.

Tauer, W. & Humborg, G. 1992. *Runoff irrigation in the Sahel Zone: remote sensing and geographic information systems for determining potential sites.* Markgraf, Weikersheim

Tseggai, A., Beyene, M. & Fre, Z. 1994. *Socioeconomic survey study of Sheeb and Wadi Labka. Draft report.* Eastern Lowlands Wadi Rehabilitation Project in Eritrea. IFAD.

UNEP. 2007. Sudan: *Post–conflict environmental assessment.* Nairobi, Kenya, United Nations Environmental Programme.

Van der Gun, J.A.M. & Wesseling, H. 1991. *Water Resources of the Wadi Surdud area: pilot study on water resources management.* Report WRAY-22. Delft, TNO and Sana'a, Ministry of Oil and Water Resources.

Van der Gun, J.A.M. & Ahmed, A.A. 1995. *The water resources of Yemen: a summary and digest of available information.* Report WRAY-35. Delft, TNO and Sana'a, Ministry of Oil and Water Resources.

Van Dijk, J.A. & Ahmed, M.H. 1993. *Opportunities for expanding water harvesting in sub–Saharan Africa: the case of the teras of Kassala.* Gatekeeper Series 40. London, IIED.

Van Mazijk, R. & Scheer, S. 1988. *Irrigatie in Tunesie, een overheidsinterventie in een traditioneel irrigatiesysteem beschouwd vanuit een interfaceperspectief,* Wageningen, LUW.

Van Steenbergen, F. 1997. *Institutional change in local water resource management: cases from Balochistan.* The Netherlands Geographical Studies. Utrecht, Faculteit Ruimtelijke Wetenschappen Universiteit.

Van Steenbergen, F. 1998. *Organized farmers; spate irrigation in Balochistan.* Available at: http://www.waterandlivelihoods.org/steenbergen1_revised.pdf

Van Steenbergen, F. & Shah, T. 2003. Rules rather than rights: self-management in intensively used groundwater systems. In: Llamas, M.R. & Custodio, E. eds., *Intensive use of groundwater: a new situation which demands proactive actions.* pp.13–31. Dordrecht, Balkema Publishers.

Van Steenbergen, F. 1997. Understanding the sociology of spate irrigation: cases from Balochistan. *Journal of Arid Environments* 35: 349–365.

Van Steenbergen, F.O. Verheyen, S. van Aarst & Mehari, A. 2008. *Spate irrigation, livelihood improvement and adaptation to climate variability and change.* IFAD/MetaMeta/UNESCO-IHE.

Varisco, D.M. 1983. Sayl and Ghayl: the ecology of water allocation in Yemen. *Human Ecology* (NY) 11: 365-383.

Varisco, D.M., Dubaie, A.R., Jazm, M., Mahyub M. & al-Khuledi, A.W. 1992. *Indigenous plant protection in Yemen: development anthropology in action.* Study commissioned by the Yemeni German Plant Protection Project (GTZ) for the Ministry of Agriculture and Water Resources (MAWR).

VBB Viak – NESPAK. 1995. *Conservation and development of land and water resources in Upper Kaha hill torrent watershed* – Watershed Management Plan, Vol. III – Socio-economic profile. Federal Flood Commission of Ministry of Water and Power.

Verheijen, O. 1998. *Community irrigation systems in the province of Balochistan.* Lahore, Pakistan: International Irrigation Management Institute (IIMI). Pakistan National Program. VI, 91 pp. (IWMI Pakistan Report R-049/IIMI Pakistan Report R-049).

Verheijen, O. 2003. *Tentative lessons learned – lessons learned from engineering approach as a development concept for spate irrigation.* Available at: http://www.spate-irrigation.org/librar/TentativeLessons.htm

Wadud, A. & Ahmad, B. 1989. *Prospects of pulses production in Rod-Kohi area in DI Khan. In:* Rod-Kohi Agriculture. Agricultural Problems and Prospects Symposium. Pakistan Agricultural Research Council (PARC). Sponsored by BARD Project of PARC and Tipan Project of NWFP Agricultural University at Agricultural Research Institute, DI Khan. 27–29 November, 1989. pp.79–84.

Wallach, B. 1988. Irrigation in Sudan since independence. *Geographical Review,* 78(4): 417–434. Available at: http://www.unsudanig.org/JAM/clusters/productive/background-docs/Sudan-Irrigation.pdf

Ward, C. 1998. *The political economy of irrigation water pricing in Yemen.* Occasional Papers on Water Management Issues, Paper 3. World Bank Resident Mission, Sana'a, Yemen. 18 pp.

Ward, C., Ueda, S. & McPhail, A. 2000. *Water resources management in Yemen.* Contribution to the CDR Yemen. Draft: 20 January 2000. 39 pp.

Westerveld, D.H. 2002. *A short technical evaluation of the present status of the Barquqa irrigation project (Tihama V) and the damage caused by the spate of July 2002 as well as some recommendations for the completion of the project.* Technical report EC Food Security Programme in Yemen. Food Security Management Unit.. GFA terra systems. Sana'a.

Wheater, H.S., 2002. *Hydrological processes in arid and semi-arid areas*. In: Wheater, H.S., Al-Weshah, R.A. (Eds.), Hydrology of Wadi Systems. IHP-V, No. 55. UNESCO, Paris.

Wildenhahn E. 1985. Traditional irrigation systems in the southwest of Saudi Arabia. *In: Traditional Irrigation Schemes and Potential for their Improvement.* Hamburg, Berlin, Verlag Paul Parey, Irrigation Symposium 1985. DVWK Bulletin 9.

Williams, J.B. 1979. *Yemen Arab Republic. Montane Plains and Wadi Rima Project: a land and water resources survey. Physical aspects of water use under traditional and modern irrigation/farming systems in Wadi Rima Tihama.* Ministry of Overseas Development, Yemen Arab Republic. Project Record 27. YAR-01-40/REC-27/79. Surrey, UK, Land Resources Development Centre. 171 pp.

World Bank. 1999. *Preparation study report – Wadi Tuban Spate Irrigation Improvement Project Phase I.*

World Bank. 2000a. *Project Preparation Report, Irrigation Improvement Project Annex G – Social Assessment.*

Word Bank. 2000b. Project appraisal document on a proposed credit in the amount of SDR 16.2 million (US$21.3 million equivalent) to the Republic of Yemen for the first phase of an Irrigation Improvement Project, 9 August, 2000. Report No: 20720-YEM. Rural Development, Water and Environment Department, Middle East and North Africa Region. 135 pp.

World Bank. 2000c. *Republic of Yemen – Irrigation Improvement Project.* Report No. PID8115. Project ID YEPE62714. Middle East and North Africa Region. 8 pp.

World Bank. 2000d. *Environmental impact assessment summary.* Spate Irrigation Improvement Project (SIIP), Republic of Yemen, Ministry of Agriculture and Irrigation. .

World Bank. 2000e. *Project Preparation Report. Spate Irrigation Improvement Project (SIIP). Annex D. Agricultural development component.* New version, April 2000. Republic of Yemen (Ministry of Agriculture and Irrigation).

WUA Liaison Section. 1994a. *The Korakan River – a study on flood irrigation.* Quetta, Balochistan Minor Irrigation and Agricultural Development Project.

WUA Liaison Section. 1994b. *Agro-economic profile of Kharan District.* Quetta, Balochistan Minor Irrigation and Agricultural Development Project. 25 pp.

Yemen Center for Social Studies & Labor Research (YCSSLR). 2003. *Implementation of Social Baseline Survey in Wadi Zabid (Hodeidah Governorate) and Wadi Tuban (Lahej Governorate).* Sana'a, Irrigation Improvement Project.

Zaqhloel, L. 1987. *Spate Irrigation in Morocco. In:* Spate Irrigation, Proceedings of the Sub–regional Expert Consultation on Wadi Development for Agriculture in the Natural Yemen. Aden, December 1987.

The Spate Irrigation Network is an international network of professionals and practitioners. It aims at bringing together the current knowledge and experience in spate irrigation over the world, connects the different professionals, practitioners and organizations working in spate irrigation, and supports implementing organizations through training and program development.

http://www.spate-irrigation.org

FAO TECHNICAL PAPERS

FAO IRRIGATION AND DRAINAGE PAPERS

1	Irrigation practice and water management, 1972 (Ar* E* F* S*)
1 Rev.1	Irrigation practice and water management, 1984 (E)
2	Irrigation canal lining, 1971 (New edition, 1977, available in E, F and S in the FAO Land and Water Development Series, No. 1)
3	Design criteria for basin irrigation systems, 1971 (E*)
4	Village irrigation programmes - a new approach in water economy, 1971 (F E*)
5	Automated irrigation, 1971 (E* F* S*)
6	Drainage of heavy soils, 1971 (E* F* S*)
7	Salinity seminar, Baghdad, 1971 (F E*)
8	Water and the environment, 1971 (E* F* S*)
9	Drainage materials, 1972 (E* F* S*)
10	Integrated farm water management, 1971 (E* F* S*)
11	Planning methodology seminar, Bucharest, 1972 (E* F*)
12	Farm water management seminar, Manila, 1972 (E*)
13	Water use seminar, Damascus, 1972 (F* E*)
14	Trickle irrigation, 1973 (E* F* S*)
15	Drainage machinery, 1973 (F* E*)
16	Drainage of salty soils, 1973 (C* E* F* S*)
17	Man's influence on the hydrological cycle, 1973 (E* F* S*)
18	Groundwater seminar, Granada, 1973 (E* F S*)
19	Mathematical models in hydrology, 1973 (E)
20/1	Water laws in Moslem countries - Vol. 1, 1973 (F* E*)
20/2	Water laws in Moslem countries - Vol. 2, 1978 (F E)
21	Groundwater models, 1973 (E)
22	Water for agriculture - index, 1973 (E/F/S*)
23	Simulation methods in water development, 1974 (E* F* S*)
24	Crop water requirements, (rev.) 1977 (C* E F S)
25	Effective rainfall, 1974 (C* E* F* S*)
26/1	Small hydraulic structures – Vol. 1, 1975 (E* F* S*)
26/2	Small hydraulic structures – Vol. 2, 1975 (E* F* S*)
27	Agro-meteorological field stations, 1976 (E* F* S*)
28	Drainage testing, 1976 (E* F* S*)
29	Water quality for agriculture, 1976 (E* F* S*)
29 Rev.1	Water quality for agriculture, 1985 (C** E* F* S*)
30	Self help wells, 1977 (E)*
31	Groundwater pollution, 1979 (C* E* S)
32	Deterministic models in hydrology, 1979 (E)*
33	Yield response to water, 1979 (C* E F S)
34	Corrosion and encrustation in water wells, 1980 (E)
35	Mechanized sprinkler irrigation, 1982 (C E* F S*)
36	Localized irrigation, 1980 (Ar C E* F S*)
37	Arid zone hydrology, 1981 (C E)
38	Drainage design factors, 1980 (Ar C E F S)
39	Lysimeters, 1982 (C E* F* S*)
40	Organization, operation and maintenance of irrigation schemes, 1982 (C E* F S*)
41	Environmental management for vector control in rice fields, 1984 (E* F* S*)
42	Consultation on irrigation in Africa, 1987 (F E)
43	Water lifting devices, 1986 (F E)
44	Design and optimization of irrigation distribution networks, 1988 (F E)
45	Guidelines for designing and evaluating surface irrigation systems, 1989 (E)
46	CROPWAT – a computer program for irrigation planning and management, 1992 (E F* S*)
47	Wastewater treatment and use in agriculture, 1992 (E)
48	The use of saline waters for crop production, 1993 (E)
49	CLIMWAT for CROPWAT, 1993 (E)
50	Le pompage éolien, 1994 (F)
51	Prospects for the drainage of clay soils, 1995 (E)
52	Reforming water resources policy, 1995 (E)
53	Environmental impact assessment of irrigation and drainage projects, 1995 (E)
54	Crues et apports, 1996 (F)
55	Control of water pollution from agriculture, 1996 (E* S)
56	Crop evapotranspiration, 2006 (E S)
57	Soil salinity assessment, 1999 (E)
58	Transfer of irrigation management services: guidelines, 1999 (E F R S)
59	Performance analysis of on-demand pressurized irrigation systems, 2000 (E)
60 Rev.1	Materials for subsurface land drainage systems, 2005 (E)
61	Agricultural drainage water management in arid and semi-arid areas, 2002 (E)
62	Guidelines and computer programs for the planning and design of land drainage systems, 2007 (E)
63	Modernizing Irrigation Management – the MASSCOTE approach. Mapping System and Services for Canal Operation Techniques, 2007 (E)
64	Manual on small earth dams. A guide to siting, design and construction, 2010 (E)
65	Guidelines on spate irrigation, 2010 (E)

Ar	–	Arabic	Multil	–	Multilingual
C	–	Chinese		*	Out of print
E	–	English		**	In preparation
F	–	French			
P	–	Portuguese			
R	–	Russian			
S	–	Spanish			

65

FAO IRRIGATION AND DRAINAGE PAPER

Guidelines on spate irrigation

Spate irrigation has evolved over the centuries and provided rural populations in arid and semi-arid regions with an ingenious way to manage their scarce water resources. It is different from conventional irrigation in many ways and therefore needs special skills and approaches that address the unpredictability and magnitude of spate floods, their high sediment load, and the associated water rights and management models.

The objective of this publication is to assist planners and practitioners in designing and managing spate irrigation projects looking at the hydrology, the engineering, the agronomy, local organizations and rules, wadi basin management and the economics. It is designed to be both a practical guidance document and a source of information and examples, based extensively on experience from across the world in places where spate irrigation is practised.

ISBN 978-92-5-106608-9 ISSN 0254-5284

9 789251 066089

I1680E/1/07.10/1100