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Improving Community Spate Irrigation

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Summary

Improving Community Spate Irrigation

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Spate irrigation is an ancient form of water management, involving the diversion of flashy spate floods running off from mountainous catchments, using simple deflectors of bunds constructed from sand, stones and brushwood on the beds of normally dry wadis. Flood flows, usually flowing for only a few hours with appreciable discharges, and with recession flows lasting for only one to a few days, are channelled through short steep canals to bunded basins, which are flooded to depths of 0.5 m or more. Subsistence crops, often sorghum, are planted only after irrigation has occurred. Crops are grown from one or more irrigations using residual moisture stored in the deep alluvial soils formed from the sediments deposited from previous irrigations. Spate systems "grow" their own soils, and rely on nutrients transported with sediments from upstream catchments to maintain fertility.

This type of agriculture is very risk-prone and requires high levels of co-operation between farmers to divert and manage the distribution of flood flows. The uncertainty stems from the unpredictable numbers, timing and volumes of floods, the occasional very large floods that wash out diversion structures, and the frequent changes to the wadi channels from which the water is diverted. Substantial local wisdom has developed in the location and construction of intakes, organising water distribution, and managing flood waters and the heavy sediment loads. In some locations large irrigation systems have developed over centuries, with what at first site appear to be rudimentary diversions and canals providing a high water diversion efficiency, and a fair measure of equity between upstream and downstream water users. Command areas may range from anything between a few hectares to over 30,000 hectares - some spate schemes rank amongst the largest farmer managed irrigation systems in the world.

Spate irrigation provides the livelihoods for large numbers of economically marginal people in areas as varied as the Middle East, Africa, South and Central Asia and Latin America and is mostly practised outside the formal state managed irrigation sector. The most comprehensive information on the current extent of spate irrigation comes from data compiled by the Food and Agriculture Organization of the United Nations (FAO). FAO data indicates that around 2.3 million ha of spate irrigation are located in 13 countries in the near and middle East and Africa, with very large areas listed in Pakistan and Kazakhstan. The FAO data are based on Government statistics that often ignore the smaller farmer managed informal schemes, and they can only be taken as indicating orders of magnitude. The true area of spate irrigation might be conservatively estimated be at least twice that recorded by current FAO statistics

Spate irrigation is a subsistence activity, with low returns, generating highly variable incomes between good and bad years, and requires very high inputs of labour to maintain intakes, canals and field systems. Where more reliable and rewarding livelihood opportunities are available periods of drought have forced farmers to abandon their schemes and local management structures have been undermined, causing spate irrigation systems to decline and disappear. This has been the case in some wealthier countries such as Saudi Arabia.

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In many arid and semi arid regions the only water available for irrigation comes from seasonal spate flows in ephemeral rivers. Storing water in dams, an obvious option to remove the uncertainty associated with unpredictability of spate flows, is rarely viable due to very high sediment loads transported by spate rivers that settle in dams and reduce there useful lives, in some cases to only a few years. In these circumstances improving existing communal spate irrigation systems, and opening up new spate irrigated areas, are attractive development options if appropriate improvement models can be identified. Only a relatively small number of public programmes to develop and improve traditional spate irrigation have been carried out. One reason has been the difficulty of justifying investments in civil engineering works on systems dominated by low value subsistence farming. A second is that it has been hard to identify successful interventions, as spate schemes are, in spite of the apparently simple technologies used, hydraulically and socially complex. These complexities were not always appreciated in past improvement and modernisation projects, which have had mixed results.

Very large numbers of existing traditional spate systems still need to be improved to reduce the excessive labour inputs required to keep them operating, and there are also large areas in arid and semi arid zones where spate irrigation could be introduced to improve crop yields in marginal rain fed areas. Water storage in the soil profile using spate irrigation may be a better option than storage in dams in arid zones where rivers carry very high sediment loads.

At present little guidance is available to development agencies, irrigation departments, Non-Governmental Organisations (NGOs) and consultants concerned with improving or developing spate systems. These guidelines are a first step towards improving this situation, by describing the strengths of traditional systems, and the approaches that have resulted in both successful and unsuccessful spate irrigation improvement projects.

Several approaches to spate irrigation development have been followed:

- Incremental farmer led improvements to traditional systems
- Spate irrigation improvement projects supported by outside agencies
- Investment in civil engineering to provide new spate irrigation infrastructure

In the last few decades extensive civil engineering investments have been made, mostly in large spate irrigation systems in Yemen, and to a lesser degree in Pakistan, Eritrea and Tunisia.

The track record of all these large civil engineering investments is at best patchy. Investments in flow division and regulation in Pakistan (for instance on the Gaj Nai in Sindh) have performed reasonably well, but the same cannot be said for modern flow diversion structures. An evaluation of 47 relatively minor spate systems built with national funding in Balochistan between 1960 and 1990 established that only 16 were still operational.

In the Tihama plains of Yemen the designs of the modernised systems became more sophisticated over time. The first scheme to be modernised, Wadi Zabid, suffered from serious water diversion and sedimentation problems, and is now operated rather like a traditional system with diversion essentially controlled by bunds constructed by bulldozers. Later schemes included effective diversion and sediment handling arrangements, albeit at a high investment cost. A profound change in some large modernised systems is that they ceased to be managed by farmers. The most extreme manifestation has been in Yemen, where the Tihama Development Authority (TDA) assumed full responsibility for operation and maintenance after the civil works on the various systems were completed. TDA has struggled to find the funds needed to carry out the maintenance, particularly removing sediments from canals, required to

Summary continued

keep the schemes functioning. In other cases where new structures have been provided responsibility for maintenance is ambiguous, particularly when local capacity to manage complex civil engineering projects is limited.

The main lessons learned from these experiences are:

- The planning and design of the rehabilitation and improvement works have mostly been carried out without effective partnership with farmers and land users. Farmers' valuable knowledge of spate irrigation, 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.
- The investment costs have been very high and it is doubtful if they can be justified in purely economic terms.
- The operation and maintenance of the larger diversion structures and canal systems, is difficult and expensive. In particular sedimentation at intakes and in canals is often not properly controlled in 'modernised systems'.
- New structures have promoted larger inequity in the distribution of irrigation water due to the collapse of traditional evolving water rights – "modernised" diversion structures give much larger control over spate flows to favoured groups of the upstream farmers.

Experience with smaller farmer managed systems, where small improvements have been introduced to improve the reliability of existing traditional intakes, for example through access to bulldozers at subsidised rates, or improvements to intakes constructed using masonry or gabions, have generally been far more successful and cost effective.

Most investments in improving, or in some cases extending spate irrigation to new areas, can only be justified as part of wider food security or poverty alleviation programmes. In these cases technical interventions, such as the construction of low cost permanent gated diversion structures, have the potential to improve spate irrigation by increasing the control over the diversion and distribution of spate water. However, they must take into account the existing irrigation practices based on traditional rights regarding the allocation and distribution of spate water, as well as the existing agricultural practices, including the important role of livestock in the farming system based on spate-irrigated agriculture.

As much of the available surface water is already effectively used for spate irrigation, the major benefits from any investment must derive from increased productivity of water use. Therefore, the emphasis in the development of spate irrigation systems should be focused first on the improvement to the reliability of existing systems of water allocation and distribution, water management, and conserving soil moisture, within the framework of existing water rights and O&M practices.

With low crop returns even in good years and the likelihood of occasional crop failures, spate-irrigated agriculture provides a precarious living. To cope with the inherent uncertainties many irrigated farming households adopt a strategy of diversifying their household economy by depending on multiple sources of income, in particular livestock and wage labour. To alleviate poverty it is not sufficient to focus only on the improvement of spate irrigation. Water is not the only constraint to improving the productivity of spate-irrigated agriculture, and many poor households only rely in part on spate-irrigated agriculture for their incomes. Successful alleviation of poverty in spate-irrigated areas also depends upon:

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- Improvement of access to inputs, extension services and marketing for spate-irrigated crops.
- Where it is possible the development of conjunctive use of ground and spate water, including access to credit for installation of (collective) wells and pumps.
- Improvement of the productivity of livestock as well as the processing and marketing of livestock products.
- Creation of opportunities for wage labour and off-farm income, in particular for landless households.

Where poverty alleviation is one of the objectives of a spate irrigation improvement project it should also develop and implement activities in these additional fields, so that poor households in spate-irrigated areas have the chance to substantially increase their incomes.
Specific recommendations for spate improvement projects are made in the final chapter of the guidelines.

The general recommendations are:

Development approach

The selection of an appropriate development concept for existing spate irrigation systems of any scale requires a clear understanding and appreciation 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 may be changed (if at all) by an improvement project.

- The socio- economic circumstances and risk avoidance strategies of the spate irrigating farmers. (If development is planned by outsiders this requires that projects be planned with adequate time and resources to allow an understanding of farmers perceptions and strategies to be developed. A long-term phased programme is required in spate irrigation improvement projects, as adaptation to changed technologies needs to be worked out with stakeholders, over a long period of time. This recommendation may often conflict with the tight, time bound, programmes of typical internationally funded development projects.)

- The local capabilities, indigenous skills, the availability of the financial resources and access to construction materials needed by farmers to carry out maintenance of improved infrastructure.

- A realistic appreciation of the scope for improving the efficiency of water diversion and distribution in traditional systems, that often already utilise a large proportion of the spate flows that are available for diversion. (Improvements in water management and improving moisture conservation in the soil profile may be as, if not more beneficial, than focussing solely on improving the efficiency of diversion).

Clearly different approaches are needed for schemes with different characteristics, levels of development, and access to external support from local or national governments or, in some countries, NGOs. However the success of any interventions will largely depend on incorporating the following principles in the development approach:

Summary continued

- In all but the largest and most technically complex schemes farmers should drive the planning, design and execution of the rehabilitation and/or 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 their particular schemes.

- 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 or possibly gabions, limiting the flows allowed to enter canals etc., while ensuring that farmers are able to finance and have access to the skills and materials needed to carry out maintenance and repair works.

- The replacement of numbers of independent traditional diversion structures by a single permanent "engineered" diversion structure eliminates the need for farmers to rebuild diversions after floods, and increases control over flood flows. However there is a strong probability that concentrating diversion at one location it will result in conflict between upstream and downstream farmers due to the inequitable distribution of available spate water that is made possible by permanent structures. It is suggested that this approach should only be adopted when downstream water users are not disadvantaged, the sedimentation problems linked with permanent structures can be managed, and for more technically advanced diversion structures, that appropriate sustainable levels of maintenance can be assured.

- Spate irrigation recharges ground water, and the use of shallow ground water for irrigation is increasing in many spate-irrigated areas. Adoption of an integrated water management approach involving both spate irrigation and irrigation from shallow ground is recommended in wadi systems where there is sufficient shallow groundwater of suitable quality to make supplementary pump irrigation a feasible option.

Simultaneously with engineering improvements agricultural improvement should be initiated to:

- Improve the yields of traditional and new drought resistant spate-irrigated crops, in particular fodder crops.
- Improvement of the productivity of livestock production, which usually provides an important part of spate irrigators' livelihoods.
- Improved access to credit, inputs, and markets for cash crops.

Recommendations for specific types of scheme

Small schemes under farmer management using traditional diversion practices

These schemes are usually found on small wadis where the flood flows can be, apart from occasional very large floods, 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. Where it is possible providing farmers with mechanisms for accessing bulldozers to repair or construct diversions is one option, provided effective arrangements for breaking of earthen spurs and bunds, and an agreed water distribution, are in place. The resources required to supply and maintain earth moving plant and provide trained operators will be too large for small projects or farmer groups, and is best organised on a district or regional basis through local government, or through the use of subsidies to allow the participation of the private sector.

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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 scour and overturning and should also 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 the downstream irrigation infrastructure.

New schemes in areas where spate irrigation is being introduced
Spate irrigation is best introduced to new areas, where formerly rain fed farmers will not generally 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, but provision of simple gated permanent structures will often be a better option when farmers do not have experience of using earthen bunds and deflectors to manage spate flows. A typical simple diversion of this type was described in Chapter 10.

Medium/large scale schemes under farmer management using traditional diversion practices
These schemes are constructed in larger wadis carrying much larger flood flows. Typically they will have numerous intakes ranging from simple deflectors at the upstream end of a wadi to diversion bunds in the lower reaches. One option is to continue to treat these schemes as a series of independent small systems, and to apply the options such as access to bulldozers or simple un-gated structures. This approach has the advantage that the farmer groups and arrangement for water distribution and maintenance can remain basically unchanged. However much large floods generating much larger forces and scouring action are encountered in larger wadis, and a higher level of engineering is needed to ensure that improved simple diversions are robust enough to provide the lifetimes expected by farmers. (Much shorter lives may be acceptable to farmers than would be provided by conventionally engineered structures in typical water projects.)

If it can be afforded a second option is to provide more permanent relatively simple gated diversion structures including a weir and scour sluice, while minimising the extent to which previously independent canals are consolidated to reduce the number of diversion required. Cost considerations will probably dictate use of a value engineering approach, including the use of fuse plugs (emergency spillway) to reduce the cost of diversion weirs. Reducing costs by providing a smaller diversion capacity but with greater efficiency than the combined capacity of the existing intakes has not proved to be acceptable to farmers and where possible should be avoided. As already mentioned this approach should only be adopted when downstream water users are not disadvantaged, the sedimentation problems linked with permanent structures can be managed, and for more technically advanced diversion structures, that sustainable levels of maintenance can be assured.

Large schemes with improved infrastructure and agency management
Large and technically complex “engineered” systems are only feasible with external support that can range from full blown agency management, to backstopping and technical support to farmers for operation and maintenance provided by local irrigation or agriculture departments. Where the high development costs can be justified quite complex permanent diversion and water control structures can be considered, although in most cases they would not be recommended. This is due to the difficulties of ensuring that a greatly improved ability to manage spate flows is not misused to the disadvantage of downstream water users, and the

Summary continued

problems of funding adequate levels of maintenance in agency managed schemes, rather than to inherent technical problems with "engineered" spate diversion structures. Agency management is vulnerable as long-term routine financing can no longer be guaranteed. Strengthening roles of both farmers and local government, and reducing the role of specialist agencies will be appropriate in some cases.

Schemes with access to sufficient shallow groundwater for irrigation
Conjunctive use of shallow groundwater removes much of the insecurity associated with spate irrigation, and allows production of cash crops with high crop water requirements, that cannot be supported by spate irrigation. However provision of credit to allow farmers to drill wells and pumps should be effectively regulated to prevent rapid over exploitation of shallow groundwater that could result in saline intrusion and the destruction of coastal aquifers. Provision of communal wells to enable poorer farmers to benefit from groundwater irrigation could be considered. Properly conducted regional water balance studies are needed before shallow well irrigation is actively promoted in spate areas.

Glossary

Ala'ala fala'ala	Irrigation sequence giving upstream users priority (Yemen)
Aqm	Earthen diversion bund constructed cross a wadi bed. Also used to describe traditional diversion spurs (Yemen and Eritrea)
Baseflow	Spring fed seasonal low flows
BCE	Before Christian Era
Bund	Embankment constructed from soil or wadi bed sediments
Ganda	Earthen diversion bund – (Pakistan)
Gham	Contribution of land owner to maintenance (Pakistan)
Kharif	Summer cropping season (wet season)
Mekemet	Conservation tillage practiced in the Sheeb area of Eritrea
Numberwar	Rule describing an irrigation sequence (Pakistan)
Rabi	Winter cropping season (dry season)
Rada'ah'	Irrigation sequence giving upstream users priority (Yemen)
Rod-Kohi or Sailaba	Form of spate irrigation practiced in Pakistan
Saroba paina	Rule describing the irrigation sequence (Pakistan)
Wadi	Valley containing an ephemeral (short duration) water course only flowing during and for a short time after spate flow events
Waqf land	Land belonging to religious trusts
Zakat	Religious tax

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1. Introduction

1.1 ORGANISATION OF REPORT

Spate irrigation involves a wide range of disciplines and many of the topics covered in these guidelines would justify substantial individual publications. In order to make the guidelines accessible and of a reasonable length they are organised around chapters containing summary descriptions of the various aspects of spate irrigation that are considered, usually with the aid of some specific examples. Access to the more detailed information contained in the large number of background papers, mostly commissioned by the community spate irrigation project, and also to an informal spate irrigation information network, can be obtained through the community spate irrigation web site.[1] Key references are listed at the end of each chapter, and the full list of documents collected for the study that preceded the preparation of this report, many from normally inaccessible "grey" literature, are listed in Chapter 14.

Recommendations for improving existing spate schemes, and developing spate irrigation in new areas, are made in Chapter 12.

1.2 SPATE IRRIGATION – OVERVIEW

Spate irrigation is carried out in hot arid and semi arid regions where evapotranspiration greatly exceeds rainfall, see Figure 1.1.

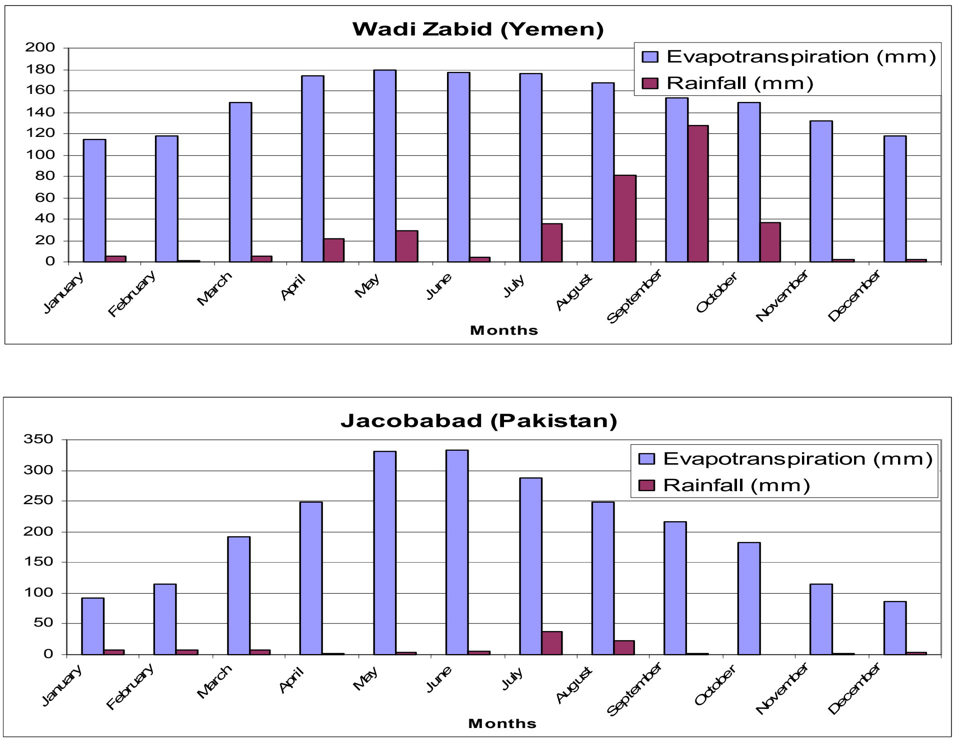

Figure 1.1 Monthly rainfall and evapotranspiration in two spate irrigated areas.

[1] http://www.spate-irrigation.org

It is an ancient form of water management, involving the diversion of flashy spate floods running off from mountainous catchments, using simple deflectors constructed from sand, stones and brushwood on the beds of normally dry wadis. Flood flows, usually flowing for only a few hours with appreciable discharges and with recession flows lasting for only one to a few days, are channelled through short steep canals to bunded basins, which are flooded to depths of 0.5 m or more. Subsistence crops, often sorghum, are planted only after irrigation has occurred. Crops are grown from one or more irrigations using residual moisture stored in the deep alluvial soils formed from the sediments deposited from previous irrigations. Spate systems "grow" their own soils, and rely on nutrients transported with sediments from upstream catchments to maintain fertility.

This type of agriculture is very risk-prone and requires high levels of co-operation between farmers to divert and manage the distribution of flood flows. The uncertainty stems from the unpredictable numbers, timing and volumes of floods, the occasional very large floods that wash out diversion structures, and the frequent changes to the wadi channels from which the water is diverted. Substantial local wisdom has developed in the siting and constructing intakes, organising water distribution, and managing flood waters and the heavy sediment loads. In some locations large irrigation systems have developed over centuries, with what at first site appear to be rudimentary diversions and canals providing a high water diversion efficiency, and a fair measure of equity between upstream and downstream water users. Command areas may range from anything between a few hectares to over 30,000 hectares - some spate schemes rank amongst the largest farmer managed irrigation systems in the world.

Spate irrigation provides the livelihoods for large numbers of economically marginal people in areas as varied as the Middle East, Africa, South and Central Asia and Latin America and is mostly practised outside the formal state managed irrigation sector. Generally it is a subsistence activity, with low returns, generating highly variable incomes between good and bad years, and requires very high inputs of labour to maintain intakes, canals and field systems. Where more reliable and rewarding livelihood opportunities are available, periods of drought have forced farmers to abandon their schemes, or local management structures have been undermined, spate irrigation systems can decline and disappear. This has been the case in some richer countries such as Saudi Arabia.

The introduction of irrigation from shallow groundwater in spate irrigated areas is a recent innovation. With the availability of relatively inexpensive pump sets this has become important in some areas in Pakistan, Tunisia and Yemen. In some areas spate water and shallow groundwater are used together, but in others the introduction of shallow wells has resulted in a neglect of the spate infrastructure, and a move towards perennial cropping, sometimes of high value cash crops.

However in many arid and semi arid regions the only water available for irrigation comes from seasonal spate flows in ephemeral rivers. Storing water in dams, an obvious option to remove the uncertainty associated with unpredictability of spate flows, is rarely viable due to very high sediment loads transported by spate rivers that settle in dams and reduce there useful lives, in some cases to only a few years. In these circumstances improving existing communal spate irrigation systems, and opening up new spate irrigated areas, are attractive development options if appropriate improvement models can be identified. Only a relatively small number of public programmes to develop and improve traditional spate irrigation have been carried out. One reason has been the difficulty of justifying investments in civil engineering works on systems dominated by low value subsistence farming. A second is that it has been hard to identify successful interventions, as spate schemes are, in spite of the apparently simple technologies used, can be hydraulically and socially complex. These complexities were not always appreciated in past improvement and modernisation projects, which have had mixed results.

Very large numbers of existing traditional spate systems still need to be improved to reduce the excessive labour inputs required to keep them operating, and there are also large areas in arid and semi arid zones where spate irrigation could be introduced to improve crop yields in marginal rain fed areas.

At present little guidance is available to development agencies, irrigation departments NGOs and consultants concerned with improving or developing spate systems. These guidelines are a first step towards improving this situation, by describing the strengths of traditional systems, and the approaches that have resulted in both successful and unsuccessful spate irrigation improvement projects.

1.3 HISTORY AND EXTENT OF SPATE IRRIGATION

Spate irrigation evolved and developed over a very long time period. The remains of diversion dams in ephemeral rivers dating from 3,000 BCE can be seen in Iran and Balochistan. It is thought that spate irrigation started in present day Yemen, when the wet climate of the Neolithic period became more arid, and has been practised there for around five thousand years. The famous Mar'ib dam in Yemen, which irrigated 9,600 ha with spate flows diverted from the Wadi Dhana, was constructed during the Sabian period in the first millennium BCE, see Box 1.1.

Box 1.1 Mar'ib Dam

It is believed that construction of the Mar'ib dam commenced around 3rd millennium BCE, and was completed in stages over the over the next 500 years. The structure had very well constructed stone abutments and irrigation off takes on both banks, which partly survive. The dam itself was constructed from rock and soil and breached on five or six occasions between the 4th and 7th century BCE when the final catastrophic breach occurred, which is described in the Holy Koran. In its final form the dam was about 18 m high and 700 m long and irrigated farmland supporting a population of between 30,000 to 50,000, growing maize, millet, barley, and other crops. The dam was intended to divert water from spate floods, rather than to store water over long periods, as storage of flood waters would have resulted in fairly rapid sedimentation. It thus functioned more like a diversion barrage than a dam.

It is reported that that large volumes of sediment were scoured out of the dam when it breached. Hehmyer (2000) suggests that the dam builders could have constructed a permanent masonry dam, but chose an earthen impounding structure that would fail when overtopped by historic floods, to prevent very large flows from damaging the irrigated area. The remains of the dam abutments and the 60 m^3/s irrigation outlets can be seen in the figure below.

Box 1.1 Mar'ib Dam (continued)

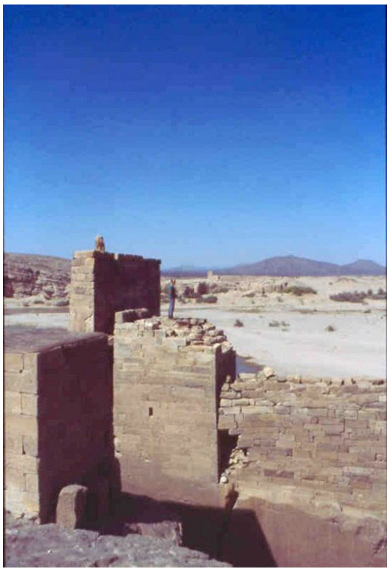

Figure 1.2 Remains of the Mar'ib dam left bank abutments and irrigation off take, Yemen

In Yemen large traditional spate systems consisting of numerous individual intakes and canals irrigating areas of up to 30,000 ha were developed in individual Wadis. Sophisticated water sharing arrangements, were formalised, with rules relating to water rights that exist in written records dating back at least 600 years. In Pakistan, spate irrigation has been practiced for a long period and it was one of the most important agricultural production systems until the end of the 18th century, when the development of perennial irrigation started under the British colonial administration. In the Province of Balochistan, there is evidence that spate irrigation was practiced as early as 3,000 BCE, whereas in the North-West Frontier Province (NWFP) and the Punjab the first spate irrigation systems were developed 330 BCE. Spate water from about 260 wadis in the north-west coastal region of Egypt was used for irrigation since the Roman times, while spate irrigation has been practised in Morocco over a similar period. In Eritrea, spate irrigation only started at the beginning of the 20th century by Yemeni migrants from across the Red Sea. In central Tunisia, farmers have irrigated their fields with diverted spate water since the second half of the 19th century, (Van Mazijk 1988).

The most comprehensive information on the current extent of spate irrigation comes from data compiled by FAO, shown in Figure 1.2.

These data indicate that around 2.3 million ha of spate irrigation are located in thirteen countries in the near and middle East and Africa, with very large areas listed in Pakistan and Kazakhstan. The FAO data are based on Government statistics that often ignore the smaller farmer managed informal schemes, and they can only be taken as indicating orders of magnitude. Some of the figures are debatable, for example in Pakistan, where spate irrigation is found in all four provinces, alternative estimates of the spate irrigated areas are more than twice that indicated in the FAO data. The very large area indicated for Kazakhstan has been questioned, and the definitions adopted to describe spate irrigation do not seem to be very consistent over the different countries. Significant areas of spate irrigation located in Ethiopia, Egypt, Kenya, Mauritania and Senegal as well as Chile and Bolivia, are not included.

The true area of spate irrigation might be conservatively estimated be at least twice that recorded by current FAO statistics. It seems likely that the development of trade spread spate irrigation techniques across the region. For example, the recent development of spate irrigation along the Eastern Lowlands in Eritrea is attributed to the arrival of Yemeni migrant eighty to one hundred years ago. Spate irrigation may also have developed independently in many places - it is found in areas as diverse and remote as West Africa, Arabia, Central Asia and China and Latin America.

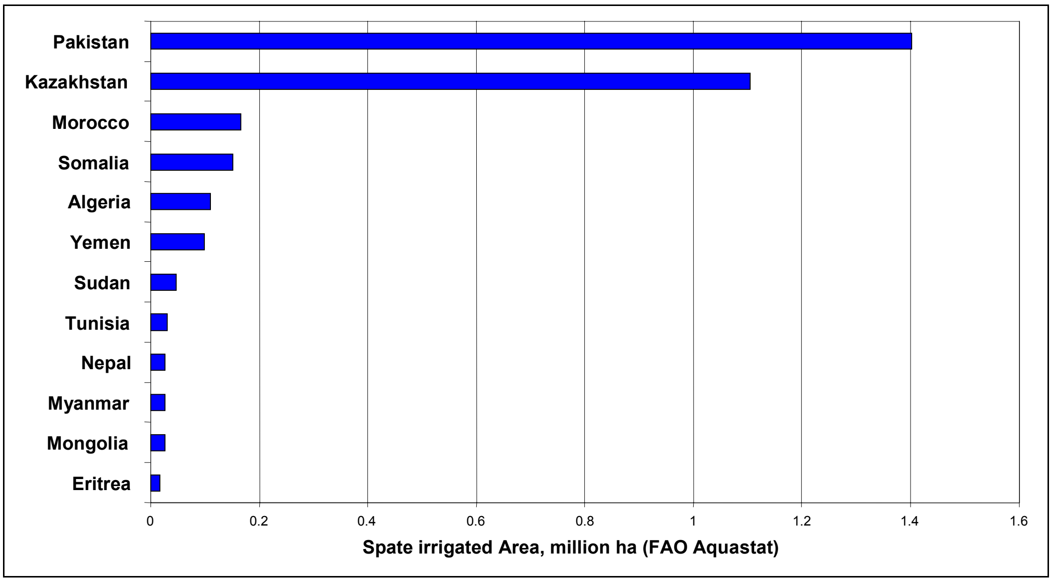

Figure 1.3 Areas under spate irrigation

1.4 DESCRIPTION OF THE RANGE OF SPATE IRRIGATION TYPES

Spate irrigation has some similarities with flood inundation systems found along valley bottoms, where crops are grown from the residual moisture following floods, and also at a smaller scale with water harvesting, where run off from small catchments is concentrated to provide water for cropping. There are two important features that distinguish spate irrigation from these other forms of flood irrigation. The first is that in spate irrigation flood water is physically diverted from wadi channels via canals to bunded fields that may be located some distance from the water course. The second is that spate irrigation is carried out at a larger scale, by groups of farmers rather than individuals, groups who need to work closely together to divert and distribute flood waters and maintain their intakes and canals. Only spate irrigation is considered in these guidelines.

A number of features can be used to characterise spate schemes. The simple and mostly physical classification described below is used to develop recommendations for improving spate irrigation.

Characteristic	Class	Note
Size of scheme	**Small**	Range from a few hectares, usually located on tributary wadis in mountain regions, to schemes on the plains supplied by small wadis, with areas ranging up to 1000 ha.
	Medium	Schemes located mostly on plains areas supplied from small/medium wadis. Command areas ranging from hundreds to say up to 5000 ha. Often a single tribe or social group will manage these schemes.
	Large	Substantial systems that may have numerous off-takes irrigating land areas of up to twenty or thirty thousand ha. Complex water sharing rules have developed in some cases that control the distribution of flows between intakes operated by different tribes, villages or social groups.
Infrastructure	**Traditional intakes and canals**	Traditional diversions consisting of deflecting spurs, or in flatter plains areas, bunds that are constructed right across the flood channel. Canals are usually short and rarely include a secondary distribution system. Water is usually passed from field to field by breaking field bunds when the ponded water reaches a predetermined depth. In Pakistan spate systems fields often have their own supply channels.
	Improved traditional systems	Farmer implemented improvements could include flow throttling structures and rejection spillways near canal heads and drop structures and flow division structures in main canals. In some areas farmers may hire bulldozers to construct diversion bunds. When outside agencies support improvements bulldozers may be provided at subsided rates, simple gabion or rubble masonry structures may be used at diversions. Improved water control structures may also be incorporated in the canal and field systems.
	Modernised and new systems	In large systems numerous traditional intakes are replaced with concrete diversion weirs, with gated canal intakes and sediment sluices. Due to the high costs of permanent structures a single permanent weir often replaces many traditional intakes. In newer schemes steep canals and sediment management structures are provided to minimise sedimentation. In new schemes, where farmers may not have the traditional skills needed to manage spate flows a range of diversion types including large semi permanent soil bunds, and small simple diversion weirs are used.
Operation and maintenance	**Traditionally managed**	Farmer mange systems without assistance from outside agencies.
	Managed by farmers with support from outside agencies	In some schemes varying levels of support from government or NGOs is provided to assist in construction and maintenance of intakes, although operation is usually left in the hands of the farmers.
	Agency managed	Some large formally farmer managed systems that have been modernised the intakes and main canal systems are operated and maintained by irrigation agencies. In Yemen some of these systems are now being “handed back to the farmers”.

Characteristic	Class	Note
Wadi flow regimes and use of groundwater	**Schemes that have access only to spate flows**	At locations where only spates occur it is necessary to divert water at high discharges if a reasonable proportion of the annual run off is to be diverted.
	Schemes that have access to significant base flows	A high water diversion efficiency can be obtained in Wadis where (a) there are small base flows for some months during and following the wet season; (b) there are large numbers of small and medium floods; and (c) the off takes are located in flat plains areas where the floods have lost momentum and may last for long periods. In these cases irrigation of areas located at the head of systems is reasonably assured, and irrigation practices at the head of systems may resemble perennial irrigation. Spate irrigation from flood flows is carried in the middle and lower wadi reaches.
	Conjunctive use of spate and shallow groundwater	Access to groundwater removes the inherent uncertainty of spate irrigation, and allows cropping of cash crops with a high water demand, such as bananas, that cannot survive for long periods between watering. Spates are still diverted for irrigation, albeit at unpredictable intervals and volumes. Spate flows enhance the recharge of the shallow aquifers.

Other classifications are possible based on, for example, the range of crops that are grown or the way water is distributed. However the framework above helps to identify three classes of scheme for which specific recommendations are developed, (Chapter 12).

2. Approaches to modernisation and improvement of spate irrigation

This chapter summarises the approaches that have been adopted for the modernisation and improvement of spate irrigation systems and the lessons learnt from these experiences. The chapter provides background to the more detailed discussion of the topics that effect spate irrigation practices presented in the following chapters.

2.1 INCREMENTAL FARMER LED IMPROVEMENTS TO TRADITIONAL SYSTEMS

Spate irrigation systems are by their nature dynamic and react to changing physical, socio-economic and agronomic conditions. Physical changes include (a) moving intakes upstream to regain command and capture base flows; (b) unstable wadi beds; (c) rising field levels; (d) damage to the irrigation infrastructure from large floods; and (e) access to "new" technologies, i.e. bulldozers, or low cost irrigation pumps. Changes in socio economic conditions include changes in the local power structures that control access and distribution of water, the availability of other more reliable livelihood opportunities, development of transport links and markets that make cash cropping viable, and policy and institutional support interventions from Government or NGOs. Changes in agronomic practice occur as new seed varieties become available, and formal and informal extension disseminate practices that increase the reliably of cropping, raise yields[2], or improve post harvest storage.

Most spate irrigation systems have evolved and been improved over time in reaction to these influences. Improvements were in most cases implemented by the spate irrigators themselves, and were developed over long time periods.

2.2 SPATE IRRIGATION IMPROVEMENT PROJECTS SUPPORTED BY OUTSIDE AGENCIES

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
- Lower level support to traditional systems
- Provision of earth moving equipment at subsidised rates.

2.2.1 Investment in civil engineering to provide new spate irrigation infrastructure

In the last decades extensive civil engineering investments have been made, mostly in large spate irrigation systems in Yemen and to a lesser degree in Pakistan, Eritrea and Tunisia.

[2] As spate irrigation is mostly a subsistence activity achieving reliability of cropping, even if yields are low, is more important than introducing using new crop varieties that achieve high yields in good years if this at the expense of the risk of a complete crop failures in bad years.

In the Tihama plains in Yemen several large spate irrigation systems were 'modernised' with World Bank support in the 1980s, i.e. Wadi Zabid, Wadi Rima and Wadi Mawr. Major investment in the Tihama continues in Wadi Siham with European Commission financing, implementing work that was identified in the 1980s but not taken up at that time. Similarly large civil works have been undertaken on large spate systems in South Yemen (formally the People's Democratic Republic of Yemen) in the 1980s with Soviet Union support. Since then the focus has moved to smaller systems in the Yemen, usually as part of larger rural infrastructure projects funded by World Bank or Arab Funds. Recently under the Irrigation Improvement Project (World Bank) two of the earlier modernised systems are being rehabilitated and, in theory, returned to farmer management.

In Pakistan the focus has been on diversion structures. Under a number of national programmes in Balochistan Province new spate diversion structures were constructed. When the national budgets dried up investment in spate systems continued under the World Bank funded Balochistan Community Irrigation and Agriculture Project. In Punjab Province a large spate system was built on the Mithawan hill torrent, using JICA (Japanese) funding.

The track record of all these large civil engineering investments is at best patchy. Investments in flow division and regulation in Pakistan (for instance on the Gaj Nai in Sindh) have performed reasonably well, but the same cannot be said for modern flow diversion structures. An evaluation of 47 relatively minor spate systems built with national funding in Balochistan between 1960 and 1990 established that only 16 were still operational.

The overriding factor behind the high proportion of failures in Balochistan was the inappropriateness of the prevailing engineering concept, which was based on controlling the flow at a single point with heavy civil engineering works rather than managing the inherently varying spate rivers. The technical designs for spate systems resembled those for perennial flows, and did not accommodate the capricious nature of the wadi channels. Some structures were not able to withstand the force of the violent peak floods. In other cases, headworks were by-passed by the braiding river. Moreover, the provisions for sediment transport were generally insufficient and the intakes silted up. Avoiding these pitfalls would have required substantial investments in large headworks, silt excluding devices and long marginal bunds. It would have been possible to control the rivers at a single point with such investments but spate makes such high investments difficult to justify.

In the Tihama plains of Yemen the designs of the modernised systems became more sophisticated over time. However, the first scheme to be modernised, Wadi Zabid, suffered from serious water diversion and sedimentation problems and is now operated rather like a traditional system with diversion and flow control bunds constructed with bulldozers.

Figure 2.1 Heavily silted canal off take in a newly modernised spate scheme

Later schemes like Wadi Mawr included effective diversion and sediment handling arrangements, albeit at a high investment cost. (See Box 2.1). In the traditional systems large floods washed out deflectors, making it difficult for upstream irrigators to control flood flows. Problems have been encountered in the modernised systems in Yemen, related to the increased capacity of upstream landowners to control spate flows when new robust diversion structures were constructed at the head of the irrigated areas. Powerful and influential groups upstream have greatly increased upstream abstractions, violating the agreed water distribution patterns.

A profound change in some large modernised systems is that they ceased to be managed by farmers. The most extreme manifestation has been in Yemen, where the Tihama Development Authority (TDA) assumed full responsibility for operation and maintenance after the civil works on the various systems were completed. TDA has struggled to find the funds needed to carry out the maintenance, particularly removing sediments from canals, required to keep the schemes functioning. In other cases where new structures have been provided responsibility for maintenance is ambiguous particularly when the local capacity to manage complex civil engineering projects is limited.

Box 2.1 Wadi Mawr, Yemen

New irrigation infrastructure in Wadi Mawr was commissioned in the mid 1980s. Located on the Tihama plain north of Hodeidah in Yemen this was one the last Tihama wadis to be modernised. The engineering infrastructure was developed using the lessons learnt from earlier spate improvement projects. It includes what is probably the most sophisticated spate irrigation intake constructed anywhere in the world. A large proportion of the annual run off in Tihama wadis consists of base and lower recession flows, and a high diversion efficiency can, in theory, be achieved with a single intake located at the head of the scheme diverting only relatively low flows. The intake was thus designed to divert up flows up to 40 m^3/s at an offtake located on the North bank of the wadi at the head of the existing irrigated area. It was estimated that this would result in 88 percent of the mean annual run off being diverted to new canals running down both banks of the wadi that would supply water to the 39 existing primary canals. A siphon transfers water under the wadi to supply a south bank supply canal.

The intake structure, see Figure 2.1 consists of a raised weir, a deep sour sluice with three gates, and four head regulator gates feeding twin sediment settling basins. The settling basins were designed to be flushed when sufficient additional water was available in floods, (the mean annual flood discharge is 300 m^3/s), to flush coarse sediments trapped by basins back to wadi. As up to 14 gates need to be operated during spates electrically powered gates were provided.

This structure provides an example of a well engineered, if expensive, technical solution to problems of diverting water from spate wadis, while at the same time controlling the diversion of coarse sediments that would settle in and block the supply canals.

However the operation of the intake and canal systems has and is being severely compromised by powerful upstream interests, who interfered with the operation of sediment flushing facilities so as not to “waste” water. Flows diverted at the intake are commandeered for use in the upstream part of the system, and a new unauthorised canal was constructed that allows water to be sold to farmers in another command area, outside the boundaries of the Wadi Mawr system. Farmers on the south bank and lower parts of the system have lost access to water that they could have formally diverted. They now have to rely on the reduced water volumes available in the infrequent very large floods that pass over the diversion weir, and are greatly disadvantaged by the operation of new system that was intended to improve the reliability of their water supply.

Figure 2.2 Wadi Mawr spate irrigation intake, Yemen

2.2.2 *Support to traditional systems*

We estimate that the extent of modernised systems is not larger than 250,000 ha, and most of the spate-irrigated areas remain farmer managed. A number of programmes have supported traditional systems - in many cases with NGOs or local government acting in catalyst roles. In Ethiopia for instance food-for-work programmes were used to extend flood canals and build new traditional diversion structures in Konso. The same happened on a larger scale in the Rehanzai Bund (Pakistan), where farmers constructed a large new soil bund with external financial support in order to spread floodwater over more than 15,000 ha of land. An example of NGO support to small scale spate systems is given in Box 2.2. The advantages of such programmes have been that they have kept local management intact, and generally relied on simple low cost improvements to the infrastructure. In some cases excessive use was made of gabion structures. The experience with gabions has not always been positive. In the Wadi Beihan Project in Yemen it was found that gabions, though marginally cheaper than structures constructed by local artisans, were difficult to repair because of the lack of local skills available. Similar experiences were noted the Western lowlands of Eritrea.

Box 2.2 An example of NGO Support to spate irrigation in Eritrea

The Norwegian Church Federation provides support to five villages with small areas of traditional spate irrigation located on the eastern lowlands of Eritrea. The project is based on the lessons learnt in an earlier project carried out in the Zulu irrigation scheme located further South on the coastal plain bordering the Red Sea.

The project has three components:

- Support to spate irrigation (40 percent)
- Training of farmers, and health improvements (33 percent)
- Village water supply (27 percent).

For the spate irrigation component the project provides tapering support over five years for building or maintaining diversions, using some gabions, and providing access to a bulldozer to construct diversion bunds. It arranges access to local Ministry of Agriculture engineers and technicians who carry out the design of simple diversions at sites selected by farmers. The project does not intervene in the canals, or water distribution, or, apart from providing some training, in the farmer's organisations – they leave the farmers to get on with it themselves.

In some of the irrigated area cash crops (melons) are grown which can be transported to markets by a new feeder road to the main road linking Massawa to Asmara. It is expected that farmers will set up a fund to provide external inputs needed for cash cropping as the project withdraws. The project does not organise this, but they have set up training programmes for men and women farmers.

The development cost for irrigating a combined area of around 2,100 ha is low at US$51/ha, but this figure should be treated with some caution as much of the irrigation infrastructure was already in place.

2.2.3 *Provision of earthmoving equipment*

Responsibility is less of an issue in support programmes involving the provision of earth moving equipment. In such programmes bulldozers and front loaders are made available for charges that typically cover part of the running costs, but not the capital costs.

Earthmoving equipment was often made available in the first place from aid-in-kind programmes. With 'bulldozer' programmes farmers remain in charge of the systems. They are given a new means to build or restore diversion works - especially earth bunds - or carry out command area improvements – including land levelling and construction of field bunds and new canals, see Box 2.3. Bulldozer programmes in Pakistan tend to be highly popular and are often the object of considerable political favouritism. The downside is that traditional water distribution systems are sometimes upset, because upstream farmers are able to build bigger and stronger bunds than they used to. Another point is that the programmes tend to unravel when the equipment needs to be replaced. There are a few examples of local entrepreneurs renting out earthmoving equipment at cost.

Box 2.3 Bulldozer support programmes in Pakistan

Provincial governments in Pakistan subsidise large bulldozer support programmes as described in Chapter 8. In Balochistan, farmers can hire a bulldozer and driver at low rates from a pool of around 300 machines located in six divisional centres. Farmers apply and pay a deposit to a district office before a work order is issued, and a bulldozer and driver are transported to their land. When a bulldozer is already working in the vicinity preference is given to nearby farmers, to minimise transportation costs. Bulldozers are used for a range of earthmoving tasks associated with both rain fed and spate-irrigated agriculture and for the construction of small dams and watering ponds.

The Balochistan Irrigation and Drainage Authority reserves bulldozer hours for farmers to build earthen diversion bunds at spate intakes. With a modest budget of US$400,000 in 2002 the bulldozer programme covered 20 small systems with a total estimated command area of 6,000 ha, i.e. an investment of US$65/ha. Although there are some resource allocation issues, bulldozer programmes are extremely popular and have played an important role in land development in Balochistan. Their widespread availability has reversed a decline in spate irrigation by underpinning the construction and maintenance of diversion bunds. The costs to sustain spate irrigation using bulldozers are extremely low when expressed on a per hectare basis.

2.3 SUMMARY OF MODERNISATION AND IMPROVEMENTS

In general 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. The record of most of these projects is poor. The main lessons learned can be summarised as follows:

- The planning and design of the rehabilitation and/or improvement works have mostly been carried out without effective partnership with farmers and land users. Farmers' valuable knowledge of spate irrigation, 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.
- The investment costs have been high and it is doubtful if they can be justified in purely economic terms.
- The operation and maintenance of the larger diversion structures and canal systems, is difficult and expensive. In particular sedimentation at intakes and in canals is often not properly controlled in 'modernised systems'.
- New structures have promoted larger inequity in the distribution of irrigation water due to the collapse of traditional water rights, evolved over many years –

"modernised" diversion structures give much larger control over spate flows to favoured groups of the upstream farmers.
- Experience with smaller farmer managed systems, where small improvements have been introduced to improve the reliability of existing traditional intakes, for example through access to bulldozers at subsidised rates, or improvements to intakes constructed using masonry or gabions, have generally been far more successful and cost effective.

In some cases government agencies have taken over the responsibility for the operation and maintenance (O&M) of diversion structures from the farmers, who often had complex, well-functioning mechanisms for the O&M of their traditional spate irrigation systems based on long experience. The role of the farmers in these schemes has changed from active irrigation managers to passive receivers of irrigation water, whose access to water for irrigation is totally dependent upon the performances of the Government agencies managing modernised spate irrigation systems.

Some of the expected benefits of the 'modernisation' of spate irrigation systems, including expansion of command area and improved yields of spate-irrigated crops, have not been achieved. This is due in part to the weak performances of some Government agencies with regard to the O&M of "modernised" systems. It is quite common for the main canals to be heavily silted due to poor initial design and a lack of maintenance desilting, resulting in canals that cannot convey the designed flows. As the field levels in some spate scheme are rising by 20 mm a year of more, command is rapidly lost, making it difficult to supply the required volumes of water to all parts of older schemes.

Several factors contribute to ineffective O&M of spate irrigation systems by Government agencies:

- Insufficient funds for the O&M of the irrigation infrastructure because (a) farmers do not pay (adequately) for the received irrigation services; or (b) the Government allocates inadequate funds for O&M.
- Ineffective use and embezzlement of the available O&M funds.
- Insufficient knowledge and skills to operate and maintain spate irrigation systems.
- Insufficient knowledge of traditional rights regarding the allocation and distribution of spate water.
- In some cases, corruption and favouritism, whereby influential and powerful farmers or landowners take more water than they are entitled to.

Although these experiences have occurred since the 1980s, they have not resulted in a major adjustment to the design of some more recently formulated spate irrigation projects. For example those implemented recently in countries such as Yemen and Eritrea are still based on the concept of providing a single expensive permanent diversion weirs to replace numbers of traditional intakes. The main reasons for the continuation of the heavy engineering approach include:

- Disbursement pressure. It is easier to spend large amount of money on a few large, capital-intensive structures than on a larger number of small, labour-intensive infrastructures.
- Preferences among engineers, government agencies and donors to design large and sophisticated infrastructure rather than low-cost structures using simple technology.
- Donors' need to implement projects in a relatively short period, leading to projects where the construction of a few large structures is preferred to the implementation

of a larger number of small project activities, over the very much longer time scales needed to allow the effective participation of the concerned farmers.

- Lack of interest and capacity among donors and government agencies to investigate and design a spate irrigation project around existing water rights, O&M practices and institutional arrangements, which have evolved over many centuries.
- In many countries the concept of participatory irrigation management is still mainly donor-driven. Many government agencies only accept it as a condition for receiving a development loan and there is a lack of experience to facilitate the effective involvement of farmers in the various stages of the development.

Most investments in improving or extending spate irrigation to new areas can only be justified as part of wider food security or poverty alleviation programmes. In these cases technical interventions, such as the construction of low cost permanent gated diversion structures, have the potential to improve spate irrigation by increasing the control over the diversion and distribution of spate water. However, they must take into account the existing irrigation practices based on traditional rights regarding the allocation and distribution of spate water, as well as the existing agricultural practices, including the important role of livestock in the farming system based on spate-irrigated agriculture.

In many of the areas in question much of the available surface water is already effectively used for spate irrigation so the major benefits from any investment must derive from increased productivity of water use. Therefore, the emphasis in the development of spate irrigation systems should be focused first on the improvement to the reliability of existing systems of water allocation and distribution, within the framework of existing water rights and O&M practices.

With low crop returns even in good years and the likelihood of occasional crop failures, spate-irrigated agriculture provides a precarious living. To cope with the inherent uncertainties many irrigated farming households adopt a strategy of diversifying their household economy by depending on multiple sources of income, in particular livestock and wage labour. To alleviate poverty in spate-irrigated areas it is not sufficient to focus only on the improvement of spate irrigation. Water is not the only constraint to improving the productivity of spate-irrigated agriculture and many poor households only rely in part on spate-irrigated agriculture for their incomes. Successful alleviation of poverty in spate-irrigated areas also depends upon:

- Improvement of access to inputs, extension services and marketing for spate-irrigated crops.
- Where it is possible the development of conjunctive use of ground and spate water, including access to credit for installation of (collective) wells and pumps.
- Improvement of the productivity of livestock as well as the processing and marketing of livestock products.
- Creation of opportunities for wage labour and off-farm income, in particular for landless households.

Poverty alleviation objectives should include these additional fields, so that poor households in spate-irrigated areas have the chance to substantially increase their incomes.

Specific recommendations for spate improvement projects are made in the final chapter of the guidelines.

(See also Section 8.1.3 in Chapter 8).

3. The socio-economic setting

3.1 INTRODUCTION

Spate irrigating communities have developed a range of livelihood strategies to cope with the large and unpredictable seasonal and inter-annual variations in water supply and crop production inherent in spate irrigation. An understanding of the socio-economic circumstances of farmers, and the coping strategies that they adopt, is needed if effective and sustainable improvements to traditional spate irrigation systems are to be developed. This knowledge can help planners and designers to avoid the unintended negative consequences of some past spate irrigation "improvement" projects.

This chapter presents a summary of the socio-economic background of farmers in spate systems, based on information from spate schemes in Yemen, Pakistan and Eritrea. More detailed information is given in Verheijen (2003). Livelihood and coping strategies adopted by spate farmers vary within and between schemes, regions and cultures. However some broad recommendations concerning the livelihood aspects of spate improvement interventions are made in Chapter 12.

3.2 POVERTY IN SPATE IRRIGATED AREAS

Most households in spate-irrigated areas are poor, with a per capita income generally less and in some cases far less, than US$1 per day. Estimated net household revenues derived for some spate-irrigated systems in Eritrea, Yemen and Pakistan are given in Table 3.1.

These figures are averages they refer to households, and mask large fluctuations. For example, farm incomes were reported to vary by a factor of three between upstream and downstream locations in non-modernised spate irrigated areas of the Tihama in Yemen, reflecting their relative access to water, Tihama Development Authority (1987). These differences will be larger now, with a new system giving upstream irrigators more control over spate flows, and the expansion of the conjunctive use of spate water and shallow groundwater for commercial cropping in upstream areas.

While a few favoured land owners located at the head of some schemes generate high incomes from commercial scale farming, most spate irrigators are poor subsistence farmers, who lack basic amenities such as potable water and sanitation, electricity and health care. High infant mortality due to malnutrition among children and pregnant women is evident in many locations, as well as anaemia, malaria and other health problems.

Table 3.1 Net annual revenues from spate irrigation

Country	Scheme	Household net annual revenue from spate irrigation US$	Note
Eritrea	Sheeb	355	Further US$165 from livestock products giving income of US$520 in a "good " year.
Pakistan	Toiwar	300	Two thirds from crop production and one third from livestock
Yemen	Shabwah Governerate	412	Increases to between US$765 to US$1,000 for households with access to pump irrigation

Data from, Hadera (2000), Halcrow (1993a, 1997,1998)

3.3 LAND TENURE

Spate irrigation systems are used by sharecroppers and tenants as well as by landowners, but there are wide variations in the pattern of tenure. Statistics from the spate irrigation systems given below show that the proportion of spate irrigated land cultivated by landowners may vary from zero to 100 percent.

Table 3.2 Irrigated areas farmed by landowners, tenants or sharecroppers

Scheme	**Percent irrigated area farmed by landowner**
Kharan District Balochistan	0
Nal Dat Balochistan	27
Toiwar Balochistan	100
Wadi Zabid, Yemen	18
Wadi Tuban Yemen	49
Wadi Rima Yemen	50

Data from World Bank (2000a), Makin (1977a), Halcrow (1994, 1993e, 1988).

3.3.1 Land ownership and distribution

In some countries, for example Ethiopia and Eritrea, all agricultural land is formally owned by the government, while in others, for example Pakistan, individuals' land rights are formally recognised and registered in government-administered cadastral records. In Balochistan, a specific form of land ownership has developed where tenants acquire permanent occupancy and partial ownership rights, as compensation for developing the land for the original landowners.

Land reforms initiated by the Eritrean People's Liberation Front (EPLF) in the latter half of the 1970s and early 1980s have changed the land ownership in Eritrea significantly by allocating small plots of land (0.5 to 1 ha) to poor families. At present, all land is government-owned, but the farmers have the on-going right to use spate-irrigated land. When the user of the land dies the usufruct right is transferred to the oldest son. Younger sons are allocated their own plots of land by the local administration when they marry.

In Yemen, land can be owned by individuals, government or trusts. In Wadi Zabid, 54 percent of the total command area is privately owned, with the remaining 46 percent belonging to private, public and religious trusts. In Wadi Tuban, 20 percent of the total command area is government-owned land, and 10 percent is Waqf land belonging to religious trusts. Following the independence of South Yemen in 1967, large land holdings were redistributed among new farmers and tenants. After the unification of North and South Yemen in 1991, the farmers working these lands lost their legal entitlements to use the land. However, the government has not enforced this change as it would make many households landless.

In general, as indicated in Table 3.3, the average land holding in spate irrigation systems are quite small.

Table 3.3 Average land holding is some spate schemes

Scheme	Average land holding, ha
Wadi Tuban, Yemen	1.4
Wadi Zabid, Yemen	2.1
Shabwah Governorate, Yemen	2.5 to 5
Sheeb Eritrea	0.5 to 1
Balochistan Pakistan	5.4 to 7.8
Nouael II project Tunisia	1.1

Data cited in Verheijen (2003)

The distribution of land within schemes varies from relatively egalitarian to highly skewed, where a few rich landowners own large tracts in the favoured upstream parts of systems that have first access to water.

Only 25 families own 53 percent the privately owned land in the modernised Wadi Zabid system in Yemen. Mostly this land is located in the upstream areas of the scheme. Another 31 percent of the total command area belong to family trusts that are often managed by the same large land holding families. Only 33 percent of irrigated land is owned by small land holders, who often have less than one hectare of land, usually located toward the tail of the scheme where irrigation is less assured. Land distribution in Wadi Tuban is less skewed as only 7 percent of the total command area belongs to landlords with more than 5 ha of land, and 49 percent of the total command area is owned by small farmers with less than one hectare. Around 55 percent (Wadi Zabid) and 25 percent (Wadi Tuban) of the households living in the spate irrigated areas do not own or lease any arable land. These landless households usually earn an income as agricultural labourers.

Further examples of unequal distribution of spate irrigated land in Balochistan are shown in Table 3.4.

Table 3.4 Percentage of land area owned by 25 percent of land owners with the largest holdings in Balochistan

Scheme	Percent of land area owned by the 25 percent of land owners with the largest holdings
Nal Dat	75
Chandia	55
Marufza	48

Data cited in Verheijen (2003)

As a result of inheritance and sales land holdings may be fragmented into two or more plots. Land fragmentation may be advantageous when different parts of the farms are irrigated and cultivated at different times, by spreading labour and management demands. Fragmented land holdings are sometimes amalgamated or enlarged by marriage, inheritance or the purchase of land with remittances from migrants.

Box 3.1 Land distribution to minimise risk

To cope with different probabilities of receiving spate water, it is common in small spate irrigation systems in Pakistan for each household to farm different plots of land, with high and low probabilities of irrigation. For instance, most landowners in the Chandia system have plots in different parts of the command area in order to reduce the risk of not receiving any flood water, as this prevents stratification and friction between up- and downstream users. A similar strategy existed in central Tunisia, where the command areas were divided into three or four sections and each landowner had a plot of land in each section. In this way, each household had access to spate water even if a small flood does not reach further that the first section of the command area. In the 1980s, however, it was no longer possible to allocate a plot of land to each household in each section as some plots had become very small, less than 0.1 ha, due to the rapid population growth. (Van Mazijk 1988).

Another strategy that was followed for a period in Eritrea was to re-allocate land at regular intervals, so as to equalise the probabilities of receiving spate flows over time. The difficulty with this is that farmers were not prepared to invest time in developing and maintaining canals and field bunds when they were shortly to be moved to other plots.

3.3.2 Tenancy and share cropping

Landowners engage tenants or share croppers to cultivate their lands if they are too old, too ill to cultivate the land themselves, or they are not resident locally. Larger landlords also hire the services of tenants or sharecroppers when they do not have sufficient labour force to cultivate the fields themselves. Female landowners, such as divorcees and widows, often find it difficult or impossible to cultivate their fields themselves due to lack of labour and draft animals, as well as cultural or religious constraints. Some landholders may be “too poor to farm” as they do not own draft animals or have access to a tractor, for the preparation and repair of the bunds. Furthermore they cannot afford inputs such as seeds to grow crops themselves. As a result, they are forced to rent their land to tenants or sharecroppers.

Share cropping is the most common arrangement in spate irrigation systems, but the “contracts” between the landowners and the share croppers vary considerably, as shown in the examples listed in Table 3.5.

Table 3.5 Share cropping arrangements in some spate schemes

Location	Share cropping Arrangement
Balochistan (Pakistan)	Sharecroppers entitled to 50 percent of the harvested crop and straw if they provide the bullocks for land preparation, and labour for planting, weeding and harvesting. Seeds may be provided by the landlords or by sharecroppers. Sharecroppers are responsible for maintenance of field bunds, and in some case reconstruction of diversion structures. In areas where it is difficult to find sharecroppers landlords may provide substantial loans. In some regions this has evolved to a form of debt-bonding, when sharecroppers have to work for the same landlord until the loan, with interest, is repaid.
Yemen (Wadi Rima and Wadi Zabid)	Sharecroppers receive one-third of the total output after they have paid 10 percent of the total output as a religious tax (Zakat) and 5 percent to the canal master. The sharecropper contributes proportionally to agricultural inputs and the maintenance of non modernised canals, but has to provide all labour, including paying for any wage labour. If major repair works are required then landowner and sharecropper pay 50 percent of the costs.
Yemen (Wadi Tuban)	Sharecroppers share is 70 to 75 percent of the harvest, but they have to provide all inputs, irrigation fees and maintenance costs.

Data cited in Verheijen (2003)

Hereditary tenancy is very common in Balochistan. In the past, owners of large tracts of land gave plots of land to other persons to develop. As compensation the developer became a hereditary tenant. The hereditary tenant loses his rights if he fails to cultivate the land and to maintain the field bunds. Landowners receive between an eighth to a quarter of the harvested crops as rent for the use of the land. The hereditary tenant is responsible for providing all inputs and labour, including the maintenance and repair of field bunds, canals and diversion structure.

Tenancy is also common in Yemen, where substantial spate-irrigated areas are owned by the State and trusts. In Wadi Zabid, some 5,000 tenants cultivate about 46 percent of the total command area, while 1,266 tenants farm 10 percent of the command area in Wadi Tuban. Annual rents may be paid in cash (US$10 to US$15 per ha) or in kind (5 to 10 percent of the crop). In Wadi Tuban and Wadi Zabid, the Government and religious trusts lease land to leading community leaders, who then sub-lease these lands to tenants and share croppers for significantly higher rents.

3.4 CROP PRODUCTION IN SPATE IRRIGATED AREAS

This topic is discussed at greater length in Chapter 6. Subsistence and low-value drought-resistant crops, such as sorghum, millet, wheat, pulses, oilseeds, cotton and melon, dominate cropping patterns in spate irrigated areas, while the production of fodder to support livestock is also priority. The sale of green fodder is an important source of cash income for farmers in the spate irrigation systems in Balochistan as well as the coastal areas of Yemen.

The yields of most spate-irrigated crops are low. In bad years some parts of command areas may not produce any crop, while the crops on other fields may only receive enough irrigation to be grown for fodder. In years with normal floods, the average yields for sorghum range between 600–2,000 kg/ha in Yemen and Eritrea, while the average yields of millet and cotton vary from 600–1,500 kg/ha and 650–1,600 kg/ha respectively in Yemen. The average yields in Pakistan are significantly lower than in Yemen and Eritrea.

The cultivation of traditional spate-irrigated crops is declining is some areas. In Pakistan and Yemen, traditional cereal crops, such as sorghum and millet, cannot compete with imported wheat which is sold at low subsidised prices in the local markets. Increasing prosperity and urbanisation, rising living standards and changing tastes has reduced the market for traditional grains, such as sorghum, that have a low socio-economic status. Often governments have promoted the cultivation of modern cash crops at the expense of traditional spate-irrigated crops by directing research, extension and credit services exclusively to these higher value crops.

Farmers mainly use local varieties, which are adapted to the local agro-climatic conditions. Seed is normally retained from one year to the next which can lead to crop diseases. However, there are few substitutes for the traditional seed varieties, as agricultural research tends to be concentrated on perennially irrigated crops. In general, farmers do not use chemical and organic fertilisers; neither do they incorporate crop residues in the soil. Most spate farmers cannot afford to use chemical fertilisers, and believe that the nutrient requirements are satisfied from the fertile sediments deposited during irrigation.

Storage losses can be high as the stored crops may be attacked fungi, insects and rodents.

Although the use of tractors is increasing, many farmers still use bullocks to prepare their fields, including the repair of field bunds and building up canal banks and constructing diversions.

Figure 3.1 Bund construction using bullocks and scraper board Eritrea

In general, farmers try to minimise the use of hired labour, and normally only family labour is used. Additional labour may need to be hired at times of harvesting and threshing. Areas with more reliable spate irrigation and regular cropping have often attracted a high proportion of landless families, who form the basis of a permanently resident labour force.

Surplus grain and cash crops are usually sold within the community, in local markets or to nomadic herders. Traders may come to a village to purchase any surplus produce, but some farmers prefer to take their produce to large urban centres in order to get a better price.

3.5 LIVELIHOOD STRATEGIES IN SPATE-IRRIGATED AREAS

With low crop returns even in good years and the possibility of crop failures always in the background, spate-irrigated agriculture makes a precarious living. Farming households adopt a number of livelihood strategies to cope with these uncertainties. The most common is the diversification of the household economy; households in spate-irrigated areas generally depend on multiple sources of income. The co-existence of livestock keeping and spate irrigation is almost universal. Small ruminants in particular are an integral component of the household production system. Other strategies include:

- Saving surplus grains from one year to the next,
- Investing in easily disposable property, such as livestock and draft animals in particular, in good years when there is crop surplus.
- Wage labour and off-farm activities provide additional household income.
- Locally available natural resources are widely exploited.
- A failed flood season often triggers substantial migration of able-bodied male family members, in search of labour.
- Following a poor season, money is borrowed from other family members, or local money lenders to purchase additional food items, or to obtain seeds for the next cropping season.
- Traditional mechanisms of solidarity and mutual assistance play an important role in the local communities.

3.5.1 Livestock

Livestock keeping is an integral component of the livelihoods strategies of most households involved in the cultivation of spate-irrigated crops. It contributes to households by:

- Provision of draught power. Oxen, and to a lesser extent camels, are traditionally used for the preparation of the fields and the maintenance of the field bunds as well as the reconstruction of the diversion structures in the riverbeds and the cleaning of the flood canals.
- Camels and donkeys are used for the transport of crop produce, drinking water and people.
- Cows, goats, sheep and poultry are raised as a source of food. Milk, dairy products, eggs, meat, wool and skins are the main livestock products, mainly used for home consumption but also sold to raise cash.
- Small ruminants, such as goats and sheep, have high reproductive rates and high degree of resilience to drought conditions. They are an important form of “saving” and can be sold in crisis situations. Oxen are also sold to bridge adverse years.
- Cattle (oxen and bullocks), donkeys and camels provide dung, which is used as fuel by making dung cakes and as a building material by mixing it with earth and straw.

The ownership of at least one pair of oxen is a good indicator of wealth. In many households it is difficult to support a pair of oxen because the farm size is too small to produce sufficient fodder to feed them in years with normal floods. At times of drought, oxen and other large ruminants are a risk, and many households do not have any choice other than to sell them, or to move to areas where fodder is available.

Figure 3.2 Bullocks in spate irritated area – Eritrea

Due to increasing farm mechanisation, the number of draught animals in spate-irrigated areas in Balochistan and some other spate irrigated regions has reduced significantly, which has had consequences for the livelihoods of many households, and the social organisation of the spate-irrigated communities. The sale of bullocks has lost its importance as a mechanism to cope with a crop failure or other crisis. The replacement of bullocks by tractors has in some cases undermined the traditional organisation of system maintenance, where every household contributed labour and animals for the re-construction of the diversion structure and cleaning of the canal system.

Some statistics on the ownership of livestock in spate irrigated areas are shown in Table 3.6.

Table 3.6 Livestock ownership in spate irrigated areas

Country	Scheme/Area	Livestock owned by "typical" or average families (There are wide variations within schemes)
Eritrea	Sheeb	On average, a typical household has 1.5–2.7 dairy cattle and 1–2 draught animals. About 30 percent of the farmers do not own bullocks.
Ethiopia	Konso	31 percent of the landowners in the Yandafero scheme have one or two oxen.
Pakistan	Chandia, Barag, Nal Dat and Marufzai	Average households owns 3–6 sheep, 5–9 goats, 1.5–3.5 cattle and 1–4 chickens. One-third of the farmers in Chandia possess bullocks and a few households in Barag and Nal Dat have a camel.
	Toiwar	90 percent of the households have on average 62 small ruminants and two cows.

Table 3.6 Livestock ownership in spate irrigated areas (continued)

Country	Scheme/Area	Livestock owned by "typical" or average families (There are wide variations within schemes)
Yemen	Shabwah Governorate	Average household owns 10–20 small ruminants, 5–10 camels and some poultry, whereas a typical household in the central region possesses 20–30 small ruminants and some poultry.
	Wadi Zabid	An average household has two cows, two calves, five goats and four sheep, while a minority of households own two oxen.
	Wadi Rima	Average households have 1.5 cows, 7.2 sheep, 1.5 donkeys and 6.4 hens, while about a quarter of the households had 2.1 oxen and about 40 percent had 3.4 goats

Data cited in Verheijen (2003)

Sharecropping is also practised in the livestock sector, with owners placing animals in the care of others in return of a proportion of the produce. Small ruminants are usually grazed on range-lands, whereas large ruminants are fed with green fodder and crop residue (i.e. straw and stalks) that are collected from the fields. To cope with shortage of fodder in the vicinity of their villages, livestock-owners may have to purchase green fodder, or migrate with their animals to other areas.

Most households use their livestock products for home consumption, although some items may be sold locally to raise cash income. In addition to spate-irrigated agriculture and livestock, bee-keeping may be another important source of income. Many households in the Shabwah Governorate in Yemen are engaged in bee-keeping, which is also an important secondary source of income among households involved in spate-irrigated agriculture in Konso in Ethiopia.

3.5.2 Use of natural resources

Water and land are obviously essential to spate-irrigated agriculture, but many other locally available natural resources play an important role in the livelihoods of farming households.

Ground water

Access to reliable sources of ground water for potable and domestic purposes through the year is a condition for the permanent settlement. Where ground water is not available permanently the local population have to leave their villages in search of water for themselves and their animals.

The use of ground water for irrigation is an important development in some areas as it greatly reduces the risks of crop failure due to the unpredictability of spate flows. Since the early 1980s, farmers have installed an increasing number of dug- and tube-wells in the command areas of spate irrigation systems in Yemen. This enables them to produce high value cash crops, such as vegetables and fruit, irrigating their field either solely with ground water or when spate water is available, in conjunction with spate water.

Due to the installation of an increasing number of tube wells the aquifers in many spate-irrigated areas are being seriously over-exploited. Households in these areas have reducing access to potable water as the level of the water table is decreasing rapidly, and an increasing number of shallow wells in the villages no longer supply water throughout the entire year. In addition, the quality of drinking water may be adversely affected, as it id effected by saline intrusion and becomes more salty.

Box 3.2 Use of groundwater for irrigation in spate irrigated areas

In the central region of Shabwah Governorate in Yemen, about 20 percent of the households have installed wells in order to reduce the risk of crop failure. Households with access to pump irrigation obtained net annual revenues that are at least twice those received by households depending exclusively on spate irrigation, (KIT 2002).

Large numbers of wells tapping shallow groundwater have been installed in the coastal areas of Yemen since the 1970s and 1980s. Many were funded by remittances from family members working in the Gulf States, or using subsidised credits from the Co-operative and Agriculture Credit Bank. A government policy to ban the import of fresh fruit and vegetables also promoted local production of fruit and vegetables. Groundwater levels have continued to drop leading to a serious risk of saline intrusion.

There are about 1,900 operational wells in the command area of Wadi Tuban, of which about 300 wells are situated in the upper reach of the Wadi. A total of between 2,000 to 2,400 wells with motor pumps have been developed in Wadi Zabid, which are mainly located in the middle and lower reaches of the Wadi, (World Bank 2000a). In addition to the cultivation of bananas and other fruit and vegetables farmers in Wadi Zabid also use ground water for the irrigation of sorghum, which is sold as green fodder at good market prices. This practice illustrates that sorghum can be an important cash crop for farmers in spate-irrigated areas and that it is not only a poor man's crop.

Both hydrogeological and financial constraints limit the extent of groundwater irrigation. The numbers of wells installed in the command areas of spate irrigation systems in Pakistan is much less than in Yemen. There are reports that tube-wells have been installed in the spate-irrigated areas of Dera Ghazi Khan as well as in a number of spate irrigation systems in Balochistan, such as Nal Dat and along the Korakan River.

The groundwater underlying the spate irrigated areas in Wadi Laba in Eritrea is reported to be too saline to be used for irrigation.

Natural vegetation

Trees and bushes play an important role in spate irrigated areas. In most systems trees and brushwood are used to construct and repair traditional spate irrigation diversion structures. Branches and even entire trees are used to strengthen diversion spurs as well as flood protection works.

Figure 3.3 Brushwood being used to protect the banks of spate canal, Eritrea

Other examples of trees are summarised in Table 3.7.

Table 3.7 Use of trees in spate irrigated areas

Country	Use of trees by spate farmers
Yemen	Each household in Shabwah Governorate has between 25 to 50 *Ziziphus spp* trees in and around their spate-irrigated fields for bee-keeping, fodder, fruits, timber, fuel wood and medicinal uses. In the Tihama trees are cut and sold directly as fuel or used to produce charcoal for sale.
Ethiopia	A large number of trees, such as *Acacia ssp* are found in the command areas of spate irrigation systems in Konso, where many beehives have been installed.
Pakistan	Trees such as the Tamarisk are common in the spate-irrigated areas Balochistan and Dera Ghazi Khan and Punjab and are used for many purposes, including use and sale as fuel either as wood or charcoal. Women for making mats, ropes and sandals use the dwarf palm. Trees with large spines, such as the *Acacia SPP*, are also used for the construction of fences around fields to protect standing crops from roaming animals and to construct corrals for the protection of livestock at night.

Information cited in Verheijen (2003)

Range lands

In addition to the cultivation or procurement of irrigated fodder crops such as green sorghum, and the use of leaves and grass found in the command area of the spate irrigation system, natural pastures are another important source of fodder. In Wadi Rima in Yemen, sheep and goats graze and browse for much of their feed along canal banks, and on fallow fields and range land. In the Sheeb area in Eritrea and the Kachhi Plain in Balochistan, livestock owners have to migrate with their animals to the pastures in the highlands for several months each year due to shortage of fodder in the vicinity of their villages.

3.5.3 Wage labour and off-farm incomes

Many households in spate-irrigated areas earn an additional income as agricultural labourers, or from other off farm activities. Most households also have to hire additional labour at critical times such as harvesting when family labour is insufficient to carry out all the field activities. The pool of wage labourers may comprise members of landless households, households with landholdings that are too small to sustain the household throughout the entire year, as well as landholding households whose fields could not be irrigated during the last flood season. Nomadic tribes and temporary migrants may also move to spate-irrigated areas during harvesting time in search of wage labour.

Wage labourers are often paid in kind, receiving a fixed portion of the harvested crop. At Nal Dat, in Balochistan (Pakistan) for example, wage labourers receive one-twentieth of the crop for harvesting, while they get one-tenth of the grain with chaff or one-eight without chaff for threshing, Halcrow (1993e, 1998). A majority of households in the Chandia spate irrigated area in Balochistan (Pakistan) have one or more household members in the civil service with low-ranking jobs, such as messengers and workmen, Halcrow (1993b). In the Sheeb area in Eritrea, a typical household accrues between 25 to 50 percent of its average annual income from wage labour, (Halcrow 1997).

Wealthier households may also be engaged in business, trade and transport, whereas poorer households in Eritrea, Pakistan and Yemen generate an income from the production and sale of handicraft products, such as pottery, mats, baskets and sandals, (Makin 1977; Hadera 2001; Nawaz 2003).

3.5.4 Migration

Migration may be needed to move livestock to areas where fodder and water can be found, which may take place annually, or in other cases only in dry years. In the Sheeb area in Eritrea, most of the population migrates every year to the highlands during the summer months in search of fodder and water and to escape the hot climate in the lowlands. Only the male members of each household remain behind to divert the floods in July and August and to plant their fields in September. Although this strategy exploits different agro-ecological zones for acquiring water, food and animal feed, important activities, such as the emergency repairs of the irrigation structures, are not undertaken at the right time due to shortage of labour. In addition, the annual costs of the seasonal migration, both in cash and labour, are substantial and could be as high as a quarter of the annual income of a typical household.

A second reason for migration is the search for waged labour by male household members.

Normally seasonal migrants return to their communities before the start of the flood or cropping season to assist in the irrigation, and the preparation and planting. Small landowners, with land that has a low probability of irrigation, migrate each year, as their landholdings cannot support their households throughout the entire year. Other landowners only have to migrate in search of labour in dry years as their landholdings produce sufficient in normal years to sustain their households. In the spate-irrigated areas of Dera Ghazi Khan and Balochistan (Pakistan), seasonal migration is common.

Farmers having spate-irrigated land may also decide to migrate permanently if they can find permanent employment elsewhere. In Pakistan the existing spate irrigation systems often cannot support entire communities. For example more than half of landholding households in Marufzai have migrated permanently to other spate irrigation systems in the Anambar valley, where they work as casual labourers, or in some cases as bonded tenants, Halcrow (1993b, 1993e).

Migration abroad, often to Saudi Arabia, was very common in spate-irrigated areas in Yemen until the first Gulf war, when most Yemenis were forced to return. In the Shabwah Governorate, up to 25 percent of extended households had a family member working in the Gulf States in 2002, (KIT 2002).

Depopulation is a constant threat in spate traditional spate irrigated areas as if the number of farmers reduces below the level needed to reconstruct diversion structures and to clean canals traditional systems cannot be sustained. Ultimately, the remaining farmers may have to abandon the entire spate irrigation, as has occurred in a number of areas in the Las Bela plains in the South of Balochistan. Migration of adult males and the difficulty in sustaining the traditional systems are cited as one of the justifications for the modernisation of the large spate systems located along the Red Sea coastal plain in Yemen.

3.5.5 Credit facilities

Indebtedness is common in spate-irrigated areas as many farmers encounter serious cash deficits during the year, or have to take on debts to survive an adverse year. Friends and relatives are usually the first source of credit. Shopkeepers and traders are another important source as many small farmers obtain seeds on credit at the start of the cropping season. The interest charged is often very high, which reflects the risks associated with spate irrigation. In the Chandia system in Pakistan farmers take loans for seeds from shopkeepers at a monthly interest rate of 5–10 percent. Farmers in Barag purchased seed on credit and paid an 80 percent mark-up. Farmers may also be obliged to sell their produce at low prices to traders, from whom they borrowed money or products, (Halcrow 1993b-c; Hadera 2001).

In the Tihama region in Yemen, the most common form of credit is the traditional system of delayed payment, acceptable to most merchants, traders and shopkeepers. Interest is not officially charged but different price levels may be negotiated depending on the time delay in payment. Traders in expensive capital equipment, such as tractors and pumps, usually offer credit up to two years. Shopkeepers and merchants give credit for shorter periods. However, deposits, security and/or a reserve of capital are required for most forms of public and private credit, and this practice precludes poorer farmers from taking advantage of credit for purchase of equipment, (Makin 1997).

Farmers in spate irrigation systems rarely have access to formal credit facilities of banks and financial institutions due to the inherent risks of spate-irrigated agriculture, and the low value of the crops that are produced. In Wadi Zabid, Yemen, only large landlords have access to credits with subsidised interest rates from the Agriculture Credit Bank, which they mainly use for the installation of tube-wells for selling ground water to smaller farmers. The latter do not have access to these cheap credit facilities as the bank requires that at least 50 percent of the investment should be self-financed by the farmer, (IIP 2002).

3.5.6 Solidarity and mutual assistance mechanisms

Traditional mechanisms of solidarity and mutual assistance still exist in the spate-irrigated areas to help people in need, struck by a calamity, or during important social events such as a wedding. However, households facing a crop failure cannot rely on mutual assistance when it occurs too frequently, or affects some landowners more than others due to the location of their fields and access to water.

Among the Tigre population living in the Sheeb area of Eritrea, groups of five to ten farmers work together on a rotation basis, whereby the farmer for whom the labour is performed provides food. Labour and oxen are also mobilised to cultivate the land belonging to widows and very poor households. Mutual self-help groups are spontaneously formed to help during field activities, or the construction of houses.

In Balochistan, it is common that labour and means of production are shared to a certain extent. Although tractors gradually take over the role of draught animals, bullocks are still lent to poor villagers for a number of days without charging a rent. Farmers without seeds at the start of the cropping season may ask their more fortunate neighbours to help them out. If a farmer cannot access his field or his field bunds have broken during the flood season, others will come to his aid by either irrigating the field on his behalf or assisting in the repair of the field bund, (Halcrow 1993 a–e; Van Steenbergen 1997).

The most prevalent solidarity mechanism in the rural areas of Balochistan is the Islamic duty, Zakat, to give part of the agricultural produce and livestock as alms to the needy, with preference given to members of the same family or clan. The payment of Zakat may also be used to finance local religious institutions, such as the mosque or religious school. Zakat is either given in cash or kind and the prescribed amount is one-tenth of the harvest of rainfed and spate-irrigated crops, one-twentieth of the harvest of pump irrigated crops and one-fortieth to one-fifth of the livestock. However, it seems that the actual donations are often less than the prescribed amounts and that not all landowners pay their Zakat on a regular basis.

Another type of assistance is to allow poor persons to pick small amounts of vegetables and melons, or to collect wheat kernels left on the threshing floor, for their home consumption. A less common practice is to give some land in usufruct to a poor relative. Relatives and neighbours offer gifts in cash and kind during special occasions, such as births, weddings and funerals, (Halcrow 1993 b–e 1998).

3.5.7 The role of women in livelihood strategies

Women play important roles in spate-irrigated agriculture and in rearing livestock. In poorer households they are often engaged as wage labourers or are involved in producing handicrafts for sale. All domestic tasks are usually the exclusive responsibility of the female household members, including the fetching of potable water and the collection of fuel wood. Women are often members of informal saving groups or other self-help groups at village level.

Roles of men and women involved in spate farming vary between regions and cultures. Some examples are summarised in Table 3.8.

Table 3.8 Men's and women's roles in spate irrigated agriculture

Country	Scheme/Area	Roles of men and women in spate irrigation
Eritrea	Sheeb	Women undertake agricultural activities, such as harvesting, threshing and transport of grains and straw, while men are usually responsible for maintaining and operating the irrigation infrastructure. A number of women are involved in mainly the sale of handicraft products, such as mats and baskets. A few women, usually widows, divorcees or former freedom fighters operate shops. Due to the policy of the Eritrean government, women are also active in community affairs, although many men reject these activities outside their houses for cultural reasons. Women have little or no authority over the slaughter or sale of livestock, but are responsible for the distribution of milk and meat to household members as well as the selling of eggs.
Ethiopia	Konso	Women play a substantial role in agriculture. In periods of drought, when men migrate in search of employment, women undertake all agricultural activities, including the maintenance of the stone terraces and irrigation. Women are also involved in petty trade and sale of fuel wood.
Pakistan	Balochistan	Almost all agricultural activities are carried out by women, except the tillage of the land. Women may assist the male members of their households with the supervision of the infield irrigation and the repair of minor damage to the earthen channels close to their fields during day light. Animal husbandry is predominantly the domain of women, who are responsible for cutting and transport of fodder, milking goats and cows, preparation of a variety of dairy products, taking care of sick and pregnant animals as well as the drying of dung for fuel. The grazing of and welfare of livestock is the responsible of men.
	Dera Ghazi Khan	Women have specialist knowledge of the intensity and magnitude of spates and rainfall in their areas, are involved in supervising irrigation, guarding infrastructure, and applying spate water at field level. Men usually carry out the diversion and distribution of spate waters.
Yemen	Shabwah Governorate	Women carry out most crop husbandry activities, including the application of farmyard manure, sowing, weeding, harvesting, threshing and removing of the crop residues from the fields. Men are responsible for the maintenance of the canals and terraces, irrigation, ploughing of the land with tractors, bee-keeping and the marketing of crop produces and livestock
	Wadi Zabid and Wadi Tuban	Men and women undertake most tasks together, including the cleaning of small canals. Generally women are responsible for the more traditional production practices, including spate irrigation, while men specialise more in the more modern agricultural practices. Raising livestock is considered to be the responsibility of women and their children. Although women are actively involved and often responsible for most agricultural and livestock activities, the marketing of any produce is exclusively reserved for men.

Information cited in Verheijen (2003)

3.6 THREATS TO LIVELIHOODS IN SPATE-IRRIGATED AREAS AND RISK COPING STRATEGIES

The livelihood strategies based on the cultivation of spate-irrigated crops in combination with additional incomes from livestock and wage labour are undermined by a number of developments:

- The importance of spate-irrigated agriculture as a source of income for many households diminishes as the average size of their landholdings decreases, due to further sub-division through inheritance.
- As more landowners install their own wells to become less dependent upon spate water for the irrigation of their fields and the gradual depopulation of communities as a result of permanent migration, the remaining farmers are often unable to mobilise sufficient labour and draught animals for the timely reconstruction of the diversion structure and the cleaning of the flood canals. The result will be that the diversion of spate water to their fields becomes more difficult and more landowners have to give up spate-irrigated agriculture, who may also decide to migrate elsewhere in search of other sources of income. Finally, the spate irrigation system ceases to function as the capacity to maintain the irrigation infrastructure is lost.
- The modernisation of spate irrigation systems, where traditional diversion structures are replaced by a concrete weir, has often had a detrimental impact for farmers in the middle and tail sections as it has become easier for upstream water users to divert more if not all spate water to their fields despite existing rules regarding the allocation and distribution of spate water.
- Degradation and widening of the riverbed may progress to such an extent that farmers are unable to reconstruct diversion structures that are high and/or long enough to divert spate water into their flood canals. Uncontrolled cutting of trees and bushes as well as overgrazing in and along the riverbed may accelerate this natural process.
- The ground water table in many spate-irrigated areas is falling rapidly due to the installation of an increasing number of dug- and tube-wells as a risk coping strategy, to become less dependent upon the unpredictable supply of spate water for irrigation purposes. The result is that older and shallower wells dry up, the quality of the ground water deteriorates, and an increasing number of fields are abandoned due to desertification. Ultimately, the population of entire villages may have not other choice than to migrate permanently as they have lost a secure access to potable water and/or arable land.

Spate irrigating communities have developed a number of risk coping strategies to cope with the uncertainties inherent in spate irrigation, summarised in text Box 3.3

Box 3.3 Risk Coping Strategies

To reduce the risks of spate irrigation, farmers have adopted a number of the following strategies:

- Diversification of the household economy. In addition to a highly variable income from spate-irrigated agriculture, households may also have income from livestock keeping and wage labour, and to a lesser extent from the sale of handicraft products.
- Spate-irrigated fields may be redistributed annually among all households with land rights.
- Households may have different plots of land with high and low probabilities of spate irrigation.
- Cultivation of draught resistant traditional crops, such as sorghum, which produce at least some fodder in draught years.
- Crop rotation may be practised – fields are left fallow during one season, in order to reduce the loss of soil fertility.
- Changing of sowing dates to control the outbreaks of pests and attacks by birds.
- Intercropping, whereby two or three different crops with different water requirements and harvesting dates are planted in the same field, so that at least one crop could be harvested in a dry year.
- Crop choice may be determined by the timing of the first irrigation.
- Use of ground water as an alternative source for irrigation.

An understating of the these strategies is essential when spate improvement projects are being planned to ensure that the proposed interventions are appropriate and do have unintended negative impacts on aspects of farmers incomes that are not directly concerned with the spate irrigated crop production.

4. The physical setting, hydrology and sedimentation

4.1 INTRODUCTION

This chapter presents a brief description of run off and sediment transport processes that influence spate irrigation practices and the design of improved diversion arrangements and canals. A summary of methods that can be used to obtain the information needed to support the design of spate irrigation systems when, as is usually the case, local data is inadequate, is given in Annex 2.

4.2 RAINFALL AND RUN OFF IN ARID AND SEMI ARID CATCHMENTS

The high intensity rainfall events that generate spate flows in wadis are characterised by large variability in space and time. Information on the spatial characteristics of rainfall in arid and semi arid zones is limited, but data from research catchments suggest a highly localised rainfall occurrence, with the spatial correlation of rainfall events approaching close to zero at distances of between 15 and 20 km, (IHP 1996).

Wadi catchments generally have sparse vegetation cover, and thin rocky soils. Soils are exposed to raindrop impact and soil crusting, which results in a low infiltration capacity. Storm rainfall generates local overland flow, which converges into wadi channel networks, generating spate flood run off events. Runoff generation is usually localised, reflecting the size of convective rainfall cells that generate run off events.[3] This presents very real difficulties when attempts are made to link flood run off with storm rainfall observed with rain gauge networks located at densities found even in relatively well instrumented catchments. This is illustrated in the example shown in Box 4.1, which demonstrates the very poor correlations between observed rainfall and run off that can be expected. Similar conclusions were drawn from a recent study in the catchments of large spate irrigation systems in the Yemen, (Arcardis 2004) and a study carried out in Eritrea, (Halcrow 1997). Estimates of flood discharges and run off volumes for spate schemes derived from conventional hydrological rainfall / run-off models should thus be viewed with a some scepticism, (IHP 1996).

Flows move down the channel network as a flood wave, over a bed that is initially dry, or has a small initial base flow. Runoff from different parts of catchments converge in the steep Wadi channels, sometimes generating multi peaked spate flows at water diversion sites in the lower reaches. Flood hydrographs are characterised by an extremely rapid rise in time, followed by a short recession, as illustrated in Figure 4.2. In this case the discharge at a spate diversion site in Wadi Rima in Yemen located close to a mountain front increased from a less than 1.0 m^3/s to around 550 m^3/s in around 30 minutes, with a second smaller peak occurring the next day. The lower water surface elevation after the flood is due to bed scour.

[3] There is some evidence, for example from the catchment of Wadi Zabid in Yemen, that some very rare extreme flood events are generated by more wide spread frontal rainfall.

Box 4.1 Rainfall run off relationships in semi arid catchments

A comparison of measured flood runoff depths with areal rainfall derived from five rain gauges located a 597 km^2 catchment in western Saudi Arabia presented in Wheater (1996) is shown below.

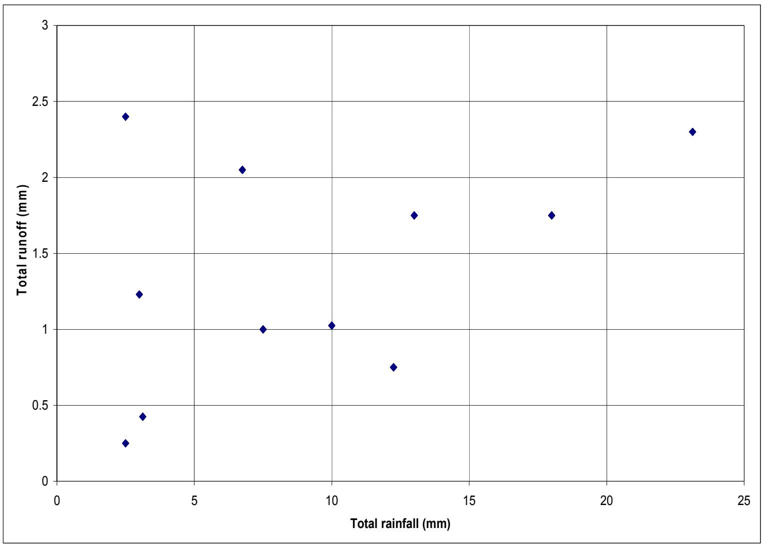

Figure 4.1 Rainfall run off relationship

The plot shows no correlation between run off measured at the catchment outlet and rainfall events observed with rain gauge network having a density of around one per 120 km^2. In this example the storm with the largest run off appears to be generated by the smallest rainfall.

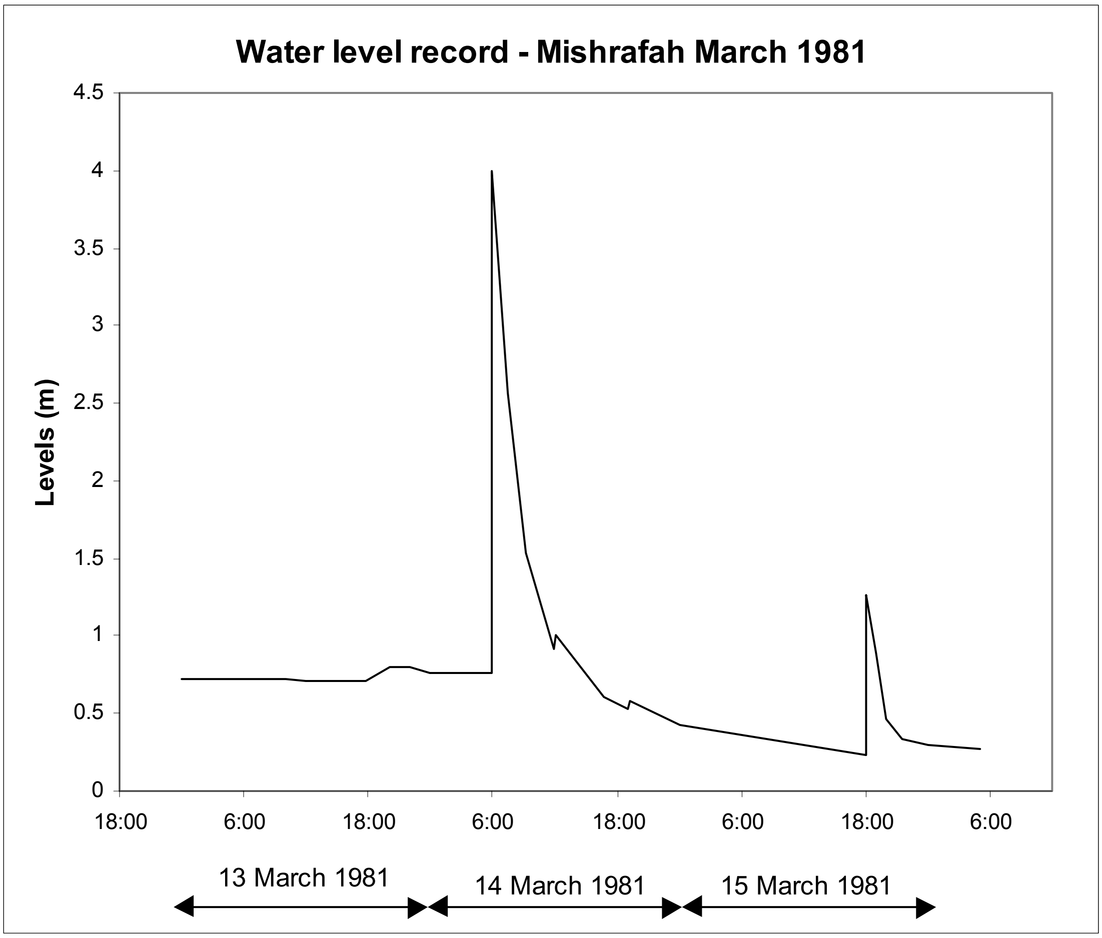

Figure 4.2 Spate flood hydrograph from Wadi Rima, Yemen

Attempts have been made to establish relationships between flood peak discharges and flood durations and flood volumes, but recent studies in Yemen and Eritrea, Arcardis (2004) and Halcrow (1997), have shown little or no correlation between peak discharges and flood volumes. Floods with a small peak discharge can have a long duration, and a large flood volume, while conversely floods with a large peak discharge can have a very short recession, and a small flood volume. Floods generated at distant parts of catchments are attenuated by the time they reach a diversion site, and the relationship between flood characteristics depends to some extent on where in catchments the flood-producing rainfall occurred. As spate floods are always characterised by a very rapid rising limb they should not be represented using classic triangular hydrograph models such as those of the US Soil Conservation Service. These do not replicate the rapid rise to peak, the rapid initial recession, or the proportions of the flood volume occurring before and after the flood peak.

Estimates of extreme flood discharges for specified return periods are needed to design wadi diversion weirs and canal intakes. Several methods can be used:

- Analysis of long term records of measured flood discharges.
- Analysis of synthetic long term run off data derived using stochastic modelling.
- "Rational" methods based on a "design" rainfall intensity, a time of concentration derived from catchment parameters, and a run off coefficient that depends on catchment conditions.

- Regional flood frequency relationships.
- Slope area calculations to estimate the size of the largest historical flood that has occurred, for which local informants can provide a reasonably reliable estimate of the flood water level.

In practice the first method is virtually never feasible as long term flow data only exists for handful of wadis world-wide. The second would only be considered for large projects that have access to specialised hydrological modelling capabilities. Rational methods are used in some areas, for example in Balochistan, Halcrow (2002b), but require information on catchment characteristics to select appropriate run off coefficients, plus rainfall intensity data, that is often not available for the catchments of many, if not most spate irrigation systems.

Regional flood frequency relationships are widely used for flood estimation in ungauged catchments. They are derived by pooling data from gauged catchments within hydrologicaly similar regions, to develop a dimensionless flood frequency relationship that can be applied to ungauged catchments in the same region. The mean annual flood discharge for the wadi being considered has to be known in order to use the method, and empirical methods can be applied to estimate this from catchment properties. In cases where little local data is available we recommend use of a regional flood frequency method, verified where possible using estimates of flood discharges derived from slope area estimates.

As with other hydrological parameters from arid and semi arid zones the distributions of flood peak discharges occurring in wadis is highly skewed. Relatively few large floods occur, and most of the annual flood run of volume occurs in floods having low or medium flood peak discharges. In some wadis flood flows are supplemented by spring fed base flows, that may persist for some weeks or months through and after the wet season. Sub surface flows in underlying alluvium may be forced to the surface by a rock bar and appear as a surface flow part way down a dry Wadi bed.

Analysis of discharge data from Wadis in Yemen, shows an approximate linear correlation between both annual and monthly flood volumes, and the number of floods that occur, if a few rare extreme floods are excluded. Similar features were observed in the results from stochastic modelling of spate runoff carried out for Wadi Laba in Eritrea, Halcrow (1997). This conclusion are very useful, as they enable annual flow volumes to be linked, albeit approximately, with the numbers of floods that occur, which will be known by farmers.

The relative proportions of base flows and flood flows in the annual hydrograph can have a large impact on the water diversion strategy that is adopted. This is illustrated in Box 4.2 that shows contrasting discharge statistics for Wadis flowing to the coastal plains located on either side of the of the Red Sea.

Box 4.2 Contrasting wadi discharge statistics

The graph shows the percent of the annual run off volume occurring in different discharge ranges for Wadi Rima in Yemen, and Wadi Laba in Eritrea, from the data reported in Makin (1977), and Halcrow (1997).

In Wadi Rima, as in the other large Tihama wadis, spring fed base flows and low flows occurring at the end of flood recessions provide a large proportion of the annual flow volume. In Wadi Rima at the time that the measurements were carried out diverting all the water flowing in the wadi at discharges less than the 15 m³/s was predicted to divert about 90 percent of the annual discharge. The intake discharge capacity of 15 m^3/s in this case represented only about 3 percent of the anticipated annual return flood peak discharge in this wadi.

Wadi Laba has a catchment area about four times smaller than Wadi Rima, and has a much lower annual flood peak discharge. As most of the annual run off occurs in spate flows, a relatively larger diversion capacity was adopted in order to divert an acceptable proportion of the annual run off. In this case an intake capacity of 35 m^3/s was selected. In this case the intake capacity is 23 percent of the estimated annual return flood peak discharge of 150 m^3/s.

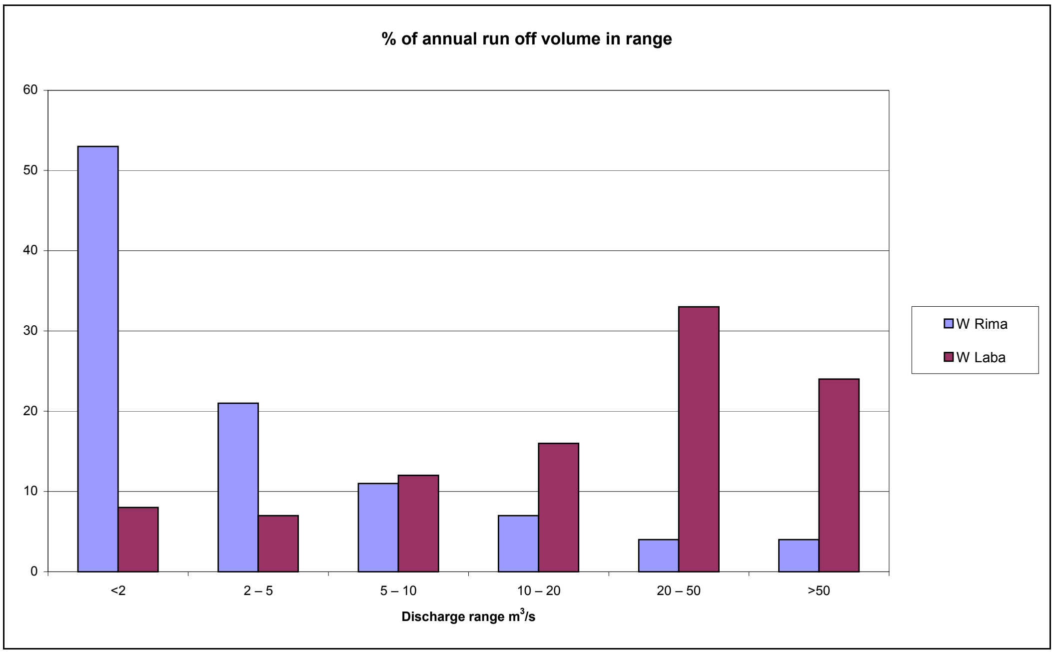

Figure 4.3 Contrasting distributions of discharges in wadi annual run off volume

Where most of the annual discharge in wadis occurs at low to medium flow rates, good diversion efficiencies can often be obtained by diverting relatively low wadi discharges to canals. When long lasting seasonal base flows can be diverted high diversion efficiencies can be achieved using simple diversion structures. This is one reason why high diversion efficiencies are obtained many traditional spate irrigation systems using multiple intakes, that wash out at high flows.

Over reliance on diversion of base and low flood flows at a single intake, a strategy adopted in many spate irrigation improvement projects, can be dangerous. In Yemen it is reported that water abstractions upstream from some diversion sites has increased and the base flows are reduced or cut off. In most cases where a new "engineered" single intake has been constructed farmers have retained their traditional diversions, and in some cases constructed new ones, to capture the flood flows passing a new diversion weir, so as to divert the largest possible proportion of wadi flows. Farmers usually want to divert as much water as possible and are not impressed with new intakes that have a limited diversion capacity.

Information on the proportion of the annual discharge occurring in different discharge ranges is needed to make rational decisions concerning the appropriate discharge capacity for intakes and canals. This is discussed further in Annex 2.

Both channel storage and high infiltration rates into the coarse alluvium that forms the beds of wadis reduce discharges as they pass down a Wadi. Water balance studies carried out for the Tihama coastal plain bordering the Red Sea in Yemen indicate that around 60 percent of groundwater recharge is derived from Wadi flows, DHV (1988). Komex (2002) report that infiltration of wadi flows provides the major source of recharge to the aquifers of both the Abyan and Tuban deltas in Yemen . Apart from a minor quantity of subsurface inflow in the alluvium of the wadis entering the coastal plain, the wadi flows provide the only source of replenishment for the aquifers. All other recharge components were merely recycling of diverted spate flows or abstracted groundwater. A water balance study carried for Wadi Turban indicated that approximately 48 percent of the surface inflow recharged the aquifer by infiltrating from wadi beds. Infiltration from spate irrigation increased the recharge by only a further 10 percent.

Estimates of seepage (transmission) losses in wadis have been made using simultaneous flow measurements at different locations. Losses, mostly measured for low flows, typically range between 1 to 5 percent of the upstream discharge per km, (Lawrence 1986; Walters 1990; Jordan 1977). Studies carried out in Yemen in the 1970s by Makin (1977) suggest that that seepage rates in seasoned traditional canals were much lower that in the main Wadi channels. If maximum use is to be made of spate flows there may be advantages in using canals, rather than the main wadi channel, to convey irrigation flows to the downstream areas of a scheme. However use of shallow groundwater for irrigation is increasing in many spate areas, and where this is the case it can be argued that seepage losses should be enhanced rather than minimised, in order to maximise groundwater recharge.

4.3 RIVER MORPHOLOGY

The catchments of spate rivers are mostly located in mountainous regions that have a higher rainfall than the plains areas, where the spate irrigation systems are usually located. A combination of poor cover, steep slopes and high intensity rainfall result in high rates of soil erosion, and a large supply of sediments to the wadi systems. The upper reaches of wadis typically have steep slopes, coarse bed materials and a very high sediment transporting capacity. Sediments ranging in size from boulders and cobbles to silts and clays are transported in large floods. In the upper reaches wadi channels are often contained within narrow valleys, and sometimes flow through gorge sections that act as natural hydraulic controls. In the larger Wadis in Yemen and Eritrea gorges located close to the mountain front are often selected for stream gauging sites, see Figure 4.4.

Figure 4.4 Wadi stream gauging site located in a gorge section close to the mountain front, Wadi Tuban, Yemen.

Wadi bed gradients usually reduce at the point where rivers emerge on to the plain areas and the decreased sediment transporting capacity results in the formation of an alluvial fan. Riverbed widths can increase by a factor of three or more in the deposition zone downstream from the mountain front, see Figure 4.5. If not incised in the alluvial fan extreme floods may cause a wadi to change its alignment, and flow off in another direction down the slope of the fan. The wide main flood channel usually contains one or more meandering shallow low flow channels, formed by the high flows of the preceding floods, that carry the lower flood recession flows. Unless “anchored” by a bend or a rock outcrop low flow channels tend to be unstable, and change their alignments from flood to flood. (See Figure 4.6).

The effects of bed seepage, channel storage, and irrigation abstractions all reduce flood flows as they pass downstream. The width of the main flood channel also tends to reduce in the downstream reaches of wadis, reflecting the lower “channel forming “ discharges. While the plains sections of Wadis are accretion zones, wadi bed level rises may be balanced to some extent by the general lowering of Wadi beds caused by large flood events. FAO (1981), report a general lowering of the bed by 0.5 m over a 50 km reach of a wadi in Saudi Arabia, that was attributed to a flood with a return period estimated as only five years.

Quite large bed level changes occur during floods, when wadi beds scour down and then reform during flood recessions. Measurements carried using scour chains in Wadi Rima, Lawrence (1983), showed the wadi bed lowering locally by up to 1.5 m and then refilling to within a few cms of its original pre flood level during the passage of a large flood. Repeat surveys of the dry wadi bed carried out over one flood season showed local changes in bed elevation of up to 1 m, with fluctuations averaged over the surveyed cross sections of around 0.3 m. Some care is needed when specifying "existing natural wadi bed levels" for the design of new wadi diversion structures. Ideally these should be based on bed level measurements carried out over several flood seasons.

The middle and lower reaches of wadis are usually contained within near vertical banks of alluvial sediment deposits, that are vulnerable to attack from high flows. Bank cutting can result in significant changes in the wadi alignment, and loss of irrigated land.

Figure 4.5 Wadi bed widening after it has emerged from a gorge onto the coastal plain (Wadi Laba, Eritrea)

Figure 4.6 Unstable low flow channels, Wadi Zabid, Yemen

4.4 WADI SEDIMENT SIZES

The transport and deposition of sediment in wadis and the canals of spate irrigation systems is strongly related to sediment sizes. At the mountain fronts wadi beds usually contain a very wide range of sediment sizes, ranging from surface layers of fine sand, silts and clays deposited from the recession of the last flood, through coarse sand gravel forming the beds of low flow channels, to shoals of cobbles and boulders. The underlying alluvium typically contains all these materials, along with very large boulders that may only be exposed and transported by the largest floods. The active beds and deposition layers from past floods can be usually observed in exposed banks or pits excavated in the Wadi beds. The wide range of sediment sizes observed on and in the bed at a typical upstream Wadi diversion site is illustrated in Figure 4.7.

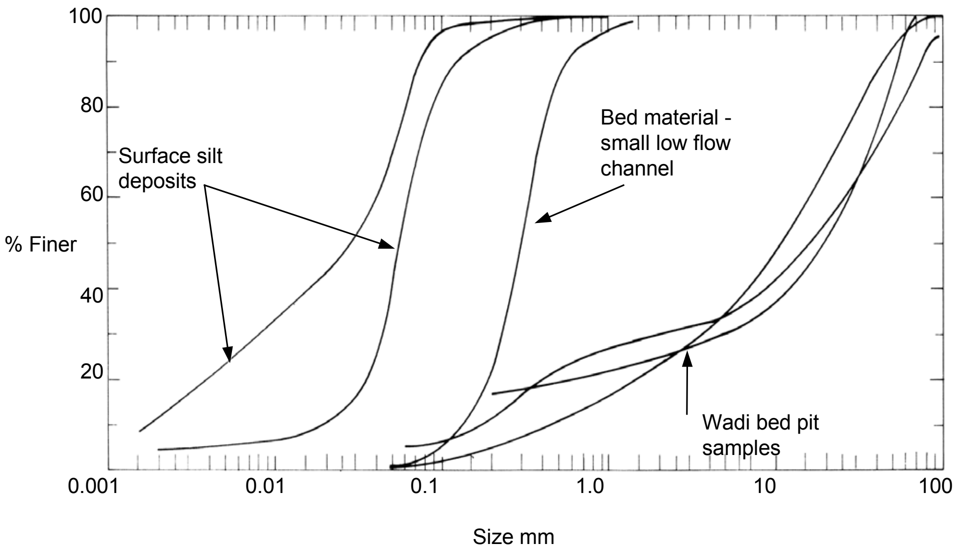

Figure 4.7 Wadi bed sediment sizes, Structure 1 Wadi Zabid, Yemen

Wadi bed material sizes reduce, and become more uniform, in the downstream direction. Wadis usually have sand beds in their lower reaches.

4.5 SEDIMENT TRANSPORT

In most spate irrigation systems only the largest floods are allowed past the irrigated area. Smaller floods are either diverted to the fields, or seep into the wadi bed. Thus although very large quantities of sediment are transported to the first diversion point, usually very little sediment is transported past the irrigated area. Coarser sediments settle in the Wadi channels and canals, and finer sediments are deposited on the fields, where farmers welcome sedimentation as a source of fertility. Spate systems build up their own soils, and the older systems are characterised by fine sediment deposits that are many metres deep.

Although management of sedimentation is a key factor in spate schemes there is very little data to assist designers in assessing sediment transport and sedimentation rates, or to design sediment management structures. The most reliable information has been derived from a small number of measurement programmes where pumped sampling equipment has been used to collect sediment samples from fixed nozzles at various depths from flood flows, Lawrence (1986) and Mace (1997).

The limited information that is available suggests that:

a. Total load sediment concentrations rising to and exceeding 100,000 ppm, or 10 percent by weight, can occur in floods in some wadis. Sediment concentrations up to 5 percent by weight in floods are common.

b. Sediment transport is dominated by the finer sediment fractions. The proportion silts and clays in the sediment load depend on the erosion status of catchments, and varies widely during and between floods, and catchments, but typically the proportion of fine silts and clay in annual sediment load varies between 50 percent and 90 percent. Silts and clays are diverted via canals to the fields, where they settle. As they are “supply controlled” fine sediment concentrations do not correlate well with wadi discharge, see Figure 4.9.

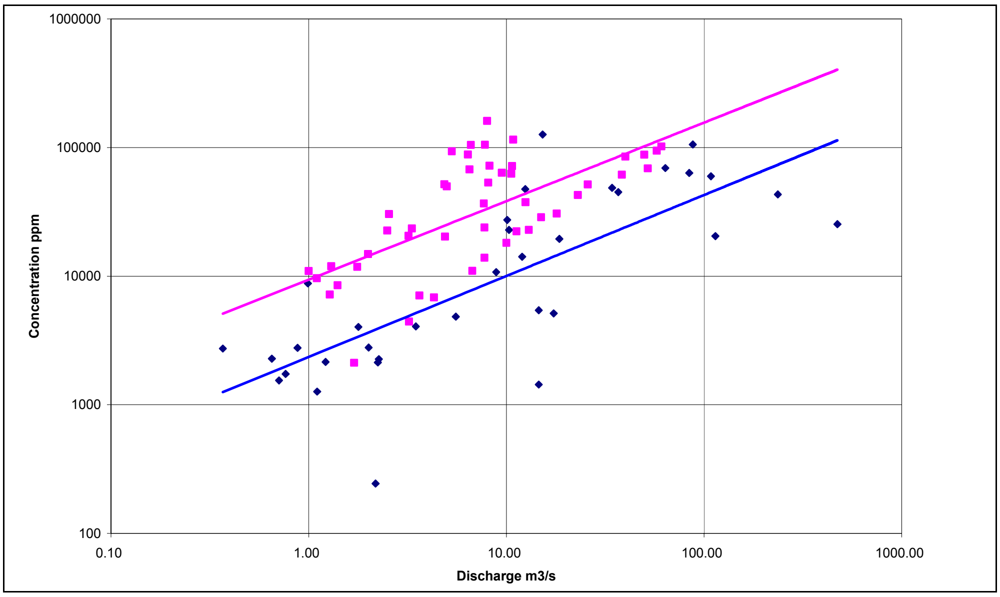

Figure 4.8 Wash load (fine sediment) concentrations for the Chakker river, Balochistan, and Wadi Laba, Eritrea[4].

c. The sand load transported in suspension in wadi flows, and that will be diverted to canals even at well designed intakes, is also quite fine, generally between 0.1 and 1 mm, when compared with the parent bed material, as shown in Figure 4.9[5].

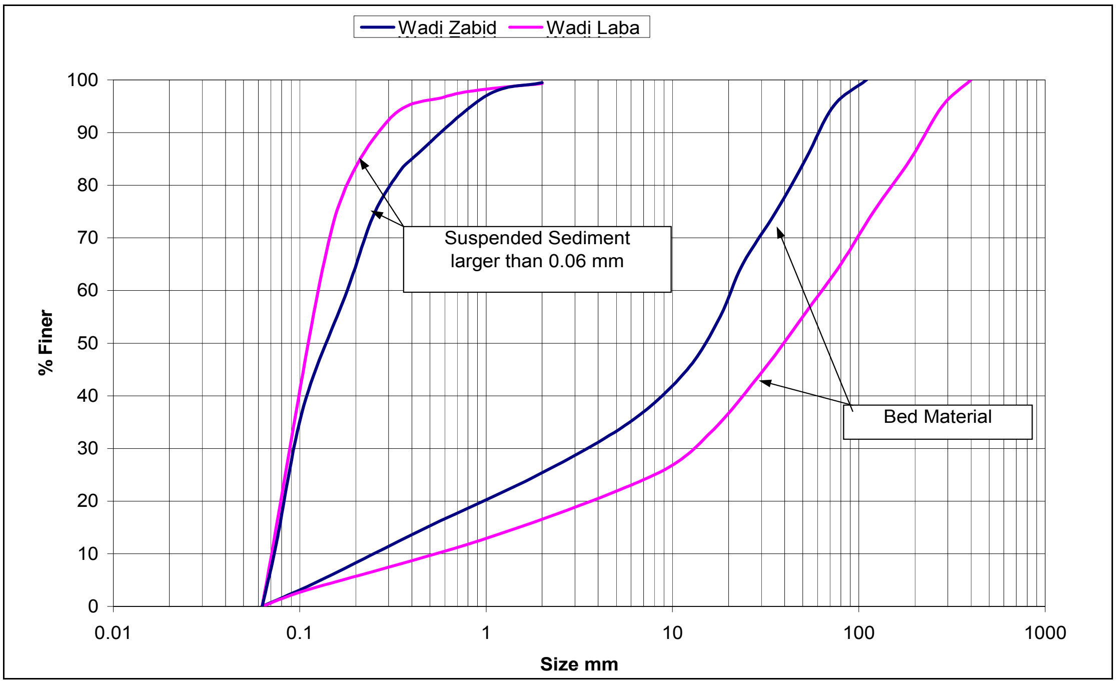

Figure 4.9 Bed material and suspended bed material (sand) load size grading for two Wadis

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[4] The similarity of the gradients of the relationships between sediment concentration and discharge for the two wadis is fortuitous. Typically the exponents in power law relationships for fine sediments transported as wash load might vary between $Q^{0.3}$ and $Q^{1.2}$.

[5] The size range and concentrations of suspended bed material can be approximately estimated from the bed material size distribution using the procedure described in HR Wallingford (2001).

d. The proportion of the sediment load represented by large sediments, that are transported by rolling and sliding along a Wadi bed, bed load, is typically only 5 percent or so of the annual load. As sediments in this size range, (coarse sand, gravel, cobbles, and in some cases small boulders), settle and block intakes and canals, estimates of bed load sizes and concentrations are needed to design intakes, canals and sediment control structures. These are usually derived using empirical equations, as measuring this component of the sediment load is usually only feasible using specialist equipment in research studies carried out in small wadis.

4.6 BUILD UP OF SOILS IN SPATE SYSTEMS

The ability to cope with high sedimentation rates in the command areas and canals is critical to the success of spate irrigation. Soils in spate areas are largely built up from wadi sediments. A relatively flat stony area can be developed over a few years by irrigating with sediment laden spate flows. In some locations soil depths of 500 mm thickness have been developed over a period of 3 to 4 years. Alluvial sediment deposits many metres thick are observed in some of the older spate irrigated areas. The rate that soil builds up varies from location to location, depending on the erosion status and sediment yield from catchments, and also with position within a scheme. Sedimentation rates are higher in the upstream fields, as they are irrigated more frequently, and also are closer to the wadi, and there are fewer opportunities for fine sediments to settle out the short steep canals linking wadis to the fields. With field to field irrigation sedimentation rates are highest in the upstream fields. Sedimentation rates in downstream areas, that rarely receive water, may be quite low.

The size range of the sediment deposits at different locations depends on the relative rates of sediment transport and deposition through the canal system. Some fine sands that are transported through the canals may settle in the upstream fields, while finer sediments, slits and clays tend to be transported further. Table 4.1 summarises information of annual rates of rise of fields in spate irrigated areas.

Table 4.1 Field rise rates in spate irrigated areas

Scheme	Annual rise rate, mm/year
Wadi Laba Eritrea (Measured 1998/99)	Upstream fields 8–32
	Middle fields 6–18
	Downstream fields 5–9
Wadi Laba Eritrea (Long term estimate)	30
Eastern Sudan	139
Baluchistan mountain systems	> 50
Wadi Zabid	Upstream fields 20–50

Data from Tesfai (2001), Ratsey (2004), Kahlown & Hamilton (1996)

Fine sediment deposits from photographed twelve days after a spate irrigation on a field in the Wadi Tuban system in Yemen are shown in Figure 4.10.

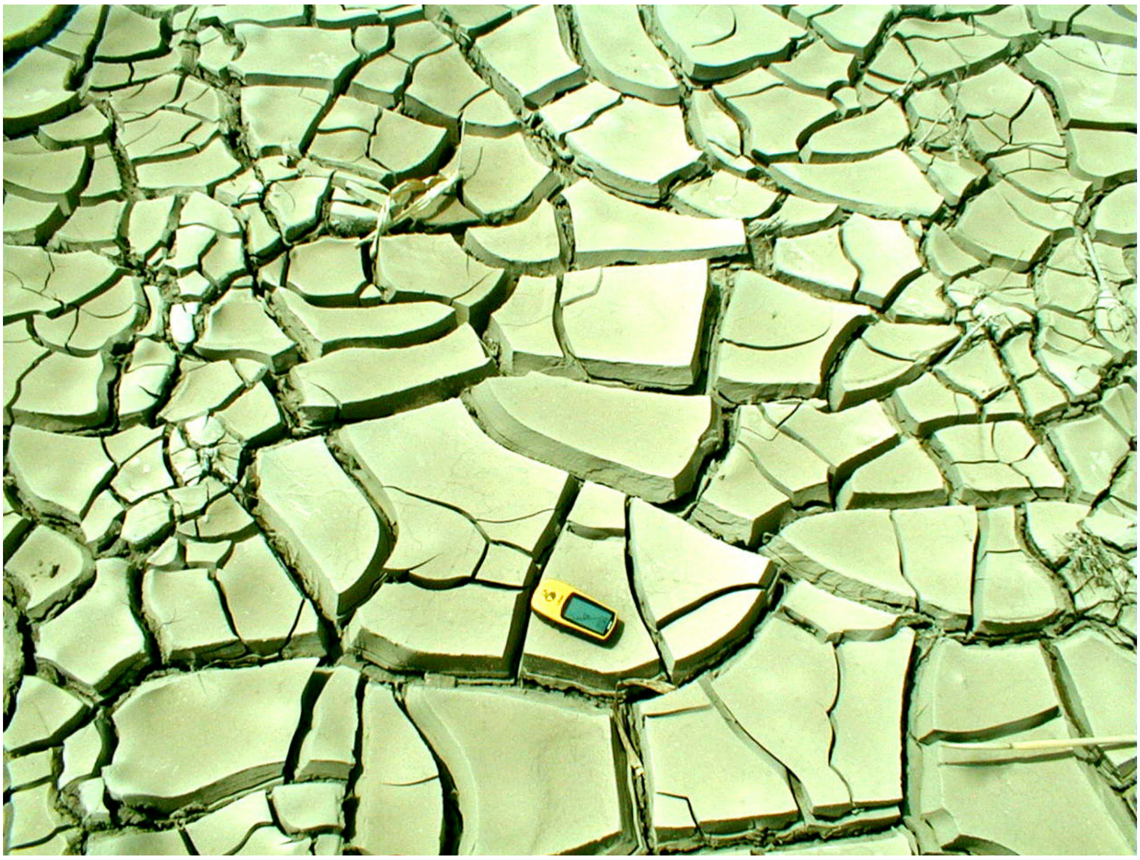


Figure 4.10 Sediment deposits – Wadi Tuban

4.7 DATA REQUIREMENTS

Hydrological data is needed to design improved water diversion structures and canals in spate schemes, although in many cases very little specific local data will be available. A summary of the methods that can be applied to derive hydrological information is given Annex 2.

5. The physical setting – soil and water management

Soil and water management in spate systems is vital for two reasons. The first is that in spate systems the soils are largely induced by human activity. They are built up from the sediments transported with the spate flows that settle when water is ponded on bunded fields. The water holding capacity and fertility of these soils is usually excellent, but soil management is required to counter land rise, maintain fertility, and in some areas to avoid soil crusting and compaction.

The second reason is the importance of moisture conservation in crop production. In spate systems irrigation before planting provides the main source of crop moisture. Conserving this moisture is essential to crop production. Good moisture conservation can have an impact on production often greater than improvements to the water diversion systems. This chapter first discusses the development of spate soils and the management of soil quality, and next field water management strategies and moisture conservation techniques.

5.1 SOIL MANAGEMENT

5.1.1 Development of spate soils

Soils in spate areas are largely built up from sedimentation in the early years of development of a spate system. They are further affected by the continuing sedimentation that is inherent to spate irrigation.

A relatively flat stony area can be developed into soils suitable for irrigation in the course of a few years by passing spate flows onto the land. Soils of 500 mm thickness have been developed over a period of three to four years. Figure 5.1 shows the foundation for a new field bund in an area being developed for irrigation on the Red Sea coastal Plain in Eritrea. Applications of heavily silted water will soon build up enough soil to enable crops to be grown.

Figure 5.1 New Land Development Sheeb Kateen, Eritrea

The difference between the levels and structure of irrigated and non-irrigated soil areas is very clear. Figure 5.2 shows the western boundary of irrigated area, with relativity deep alluvial soils, and the contrasting lower sandy desert scrub land at the western edge of the irrigated are in Wadi Zabid, Yemen.

Figure 5.2 Boundary between irrigated and non-irrigated land showing the accumulation of alluvial sediment deposits, Wadi Zabid Yemen

Spate soils are influenced by number of factors: irrigation practices, climate, the conditions in the source catchment, the underlying material, vegetation and time. The location of the bunded plots within the irrigation system is an important factor determining soil thickness and soil texture. Sedimentation rates tend to be higher in the upstream areas. Tesfai and Sterk (2001), while measuring sedimentation rates on fields in Sheeb (Eritrea) found that sedimentation rates ranged from 8.3–31.6 mm/year in upstream fields, 6.0–18.0 mm/year in midstream fields to 5.2–8.6 mm/year in downstream fields. These differences are explained by the generally higher frequency and larger volumes of irrigation on the fields in upstream areas. Average siltation rates on spate irrigated fields in systems in Yemen Eritrea Sudan and Pakistan ranging between 6 mm to more than 50 mm a year are quoted in Table 4.1 of Chapter 4.

Large sediment particles tend to settle out in the canals near to the wadi intakes. However sand may be transported to and be deposited on fields close to wadi intakes to form coarse sandy soils. Finer sediments, with lower settling velocities, are transported in suspension and can travel with the water to more remote locations. Finer sediments, silts and clays, are mostly transported through the canal systems and are deposited on the fields. As a result soil textures, and water retention capacity varies within the spate systems, with soils in the middle part of the wadi alluvial fan normally having the best water retention capacity. For Wadi Abyan in Yemen water retention capacities for different soil texture classes were compared, Table 5.1, highlighting the relatively low water retention capacity of the sandy soils in the upstream areas.

Table 5.1 Available water in different soils in Abyan Delta

Soil textural class	Available water in 1 m depth of soil (mm)
Loamy sand	39
Sandy loam	83
Silt loam	163
Clay loam	170
Silty clay loam	202

Data from Rijks (1965), quoted in Mu'Allem (1987)

The constant sedimentation of spate systems can turn from a blessing into a curse, as over the longer term it causes field levels to rise, and for fields to go out of command. In traditional systems this can be compensated over the medium term by moving intakes further upstream and by constructing higher bunds in flood canals to raise water levels. However, in many long established spate systems one finds areas that are abandoned as they have gone out of command and can no longer be irrigated. To mitigate land rise farmers move soil to the field bunds while levelling their fields, see Figure 5.3. In Pakistan material is scoped from the inner side of the bund, leaving a depression of typically 6–8 m wide on the inner side of a bund. This depression holds the first thrust of water, and helps to control sedimentation.

Figure 5.3 Field bund being strengthened with soil scraped up from irrigated land, Eritrea

Sedimentation within the bunded fields tends to form a series of approximately levels terraces, Figure 5.4, with drops in level between the fields, necessary for the field to field irrigation system to function, (Williams 1979).

Figure 5.4 Spate irrigated fields in Wadi Zabid, Yemen

In field-to-field irrigation systems plots are inundated for a short period. A field bund is then breached to allow water to travel to the next plot, before all water infiltrates in the first field. Under these circumstances fields do not need to be fully levelled and only coarse land levelling is carried out by farmers. Farmers often assume that the floodwater will level the lower spots of the fields by depositing more sediment in the low spots, but this is not always the case, (Tesfai 2001).

Too large variations in the levels within fields lead to over watering and leaching of plant nutrients at lower levels and under watering at higher levels. This results in a poor water use efficiency and typically uneven crop growth and yields within the same field, (Goldsworthy 1975); (Williams 1979); (WS Atkins 1984); (Mu'Allem 1987). Crops in the low-lying flood irrigated fields do not grow well and suffer from nitrogen deficiency, (Mu'Allem 1987). The process of moving floodwater from field to field leads to irregularities in the land surface unless water distribution structures that prevent or limit scour are used, making it impossible to regulate the depth of water application, (WS Atkins 1984).

It is common practice for fields to be maintained at a slight slope. In Balochistan this is done to ensure that any rainfall will collect at one edge of the field, making cultivation possible in the lowest part of the field in years when there are no significant floods, van (Steenbergen 1997). Also, individual fields may retain a minor slope to enable water to flow easily from field to field, (Makin 1977).

5.1.2 Soil management

Soils in spate systems have generally good water holding capacities: loams, silty loams, sandy loams and sandy clays are common. In some areas – such as the Wadi Abyan in Yemen - wind erosion has had a negative impact on soils, as the resulting sand layers reduce water-holding capacity. Wind erosion has also caused fine particles on well-established loamy areas to be blown away. This problem is more severe in areas that are only cultivated infrequently – in particular the tails of the spate systems.

Infiltration rates in irrigated soils vary with soil texture, density and soil management practices, (Williams 1979). Infiltration rates range from 7.5–20 mm/hour in highland systems in Balochistan (Kahwlon and Hamilton 1996) to 39 mm/hour in Sheeb, Eritrea (Tesfai, 2001) to 40–60 mm/hour in Wadi Rima, Yemen (Makin 1977a). They are reported as moderately rapid to rapid in Wadi Bana and the Abyan Delta (WS Atkins 1984). As discussed in Section 5.2.3 pre-irrigation ploughing can significantly increase infiltration rates.

Soil fertility in spate areas is not generally a major issue. Fertility is ensured by the regular replenishment of fine silts, carrying organic material eroded from the catchments. Farmers in spate systems are often able to correlate the sediment contents of the flood with the part of the catchment where the flood originates. In some exceptional cases farmers even apply a policy of closing the system for spate flows that are known to carry large quantities of salt.

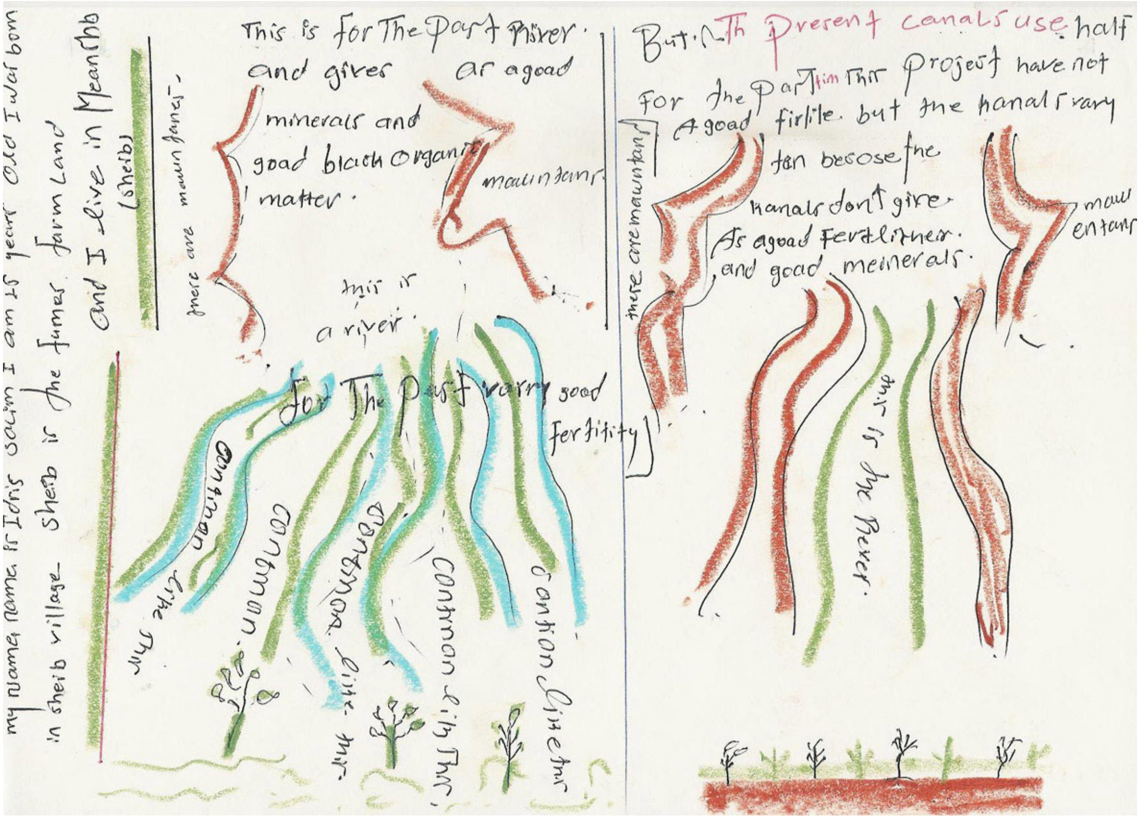


Figure 5.5 School children's assessment of soil fertility problems in Wadi Laba, Eritrea

In the Wadi Laba system in Eritrea there was large concern among farmers that a small gravel trap, constructed as part of the modernisation of the system, would also intercept the fertilising silts. In reality only a tiny fraction of the fine sediment load entering the canal network could have ever been trapped in the settling basin. These concerns were reflected in a school children's assessment of the system, Figure 5.5, carried out as part of a recent IFAD appraisal. This experience illustrates how easily misunderstandings can arise between farmers and the engineers responsible for improving a spate system.

The most common soil fertility problems are the low availability of phosphate and unavailability of some micro-nutrients, (WS Atkins 1984; Tesfai 2001). As the floodwater deposits sediments with each irrigation, there is no time for weathering and pedogenetic processes to take place, (Tesfai 2001; Tesfai and Sterk 2001). Some deep soils may restrict root growth (particularly taproots) because of stratification caused by frequent textural changes in the soil profile, (Mu'Allem 1987). Soils in spate systems are often relatively low in organic matter content, 0.8–0.9 percent in the Sheeb area, Eritrea, (Tesfai 2001), and less than 1 percent in most surface horizons in Wadi Rima and elsewhere in Yemen, (Girgirah *et al*., 1987). Organic matter is one of the major sources of soil fertility particularly for nitrogen and phosphorus. The low organic matter content of the soils is often related to the sparse natural vegetation in the catchments. The small amount of organic material available is decomposed rapidly in the high temperatures that prevail in many areas. Tesfai (2001) suggests that soil fertility could be improved by incorporating organic fertilisers and crop residues into the soil, only feasible if other types of fodder are available; by growing leguminous crops; and by practising crop rotation.

5.2 FIELD WATER MANAGEMENT AND MOISTURE CONSERVATION

Field water management and moisture conservation in spate systems are as important as effective water diversion. As much as possible the floodwater should be spread in a controlled, non-erosive manner. Moisture conservation is important because crop yields can be severely depressed by moisture deficit. Farmers in the Sheeb system in Eritrea estimated that someone owning his own bullocks would have a yield that was 30 to 100 percent higher than framers who did not own bullocks. The reason for this difference was that with draught animals of one's own one could plough fields, and repair bunds, after every irrigation, hence vastly increasing moisture retention. Research in Yemen suggests that if land is not ploughed within two weeks after irrigation up to 30 to 40 percent of moisture may be lost.

So far interventions in spate irrigation have mostly concentrated on improving the diversion of spate flows. Water management within the command area has often been treated as a 'black box'. In spite of substantial potential gains, there has been little attention to command area development, improved water distribution or facilitating moisture conservation. This section discusses water distribution within the command area, field water application and moisture conservation measures.

5.2.1 Field water distribution strategies

The nature of spate irrigation means that farmers cannot follow a predetermined irrigation schedule where water quantities are applied to a crop when it is needed. This does not mean that water distribution within the command area is either haphazard or unplanned. Water distribution is regulated by prevailing water rights and rules and generally seems to follow a number of principles:

- Rapidly spreading the available flows, and preventing spate water rapidly disappearing in low-lying areas.
- Dividing the floods in manageable quantities so as to avoid erosive flows and gully formation.
- Ensuring that large enough water volumes to irrigate the downstream areas are conveyed in the short time that spate flows are available.

Beyond these general principles water distribution within the command area is determined by (a) the prevailing local custom, sometimes derived from Islamic water law, (upstream users have priority); (b) whether water is distributed field-to-field, or each field has its own inlet from a canal, and (c) whether the flood flows are concentrated in a small area, or spread over an extensive area. Water rights are discussed in Chapter 7.

Field-to-field or individual field off-takes

In field-to-field irrigation there are no secondary or tertiary canals. All the flow in a canal is diverted to a group of bunded fields, by an earthen bund that blocks the canal. When the upstream field of the group commanded by the canal bund is irrigated, water is released by making a cut in downstream field bund to release water to the next field. This process is repeated until all the fields in command have been irrigated. If the spate continues then the canal bund is then broken and the process is repeated at a bund constructed further down the canal at the next diversion point.

The alternative is to supply fields from field inlets on secondary canals. In Yemen and in the Eastern Lowlands in Eritrea field-to-field systems are common, whereas in

Pakistan individual field intakes are the norm. Both systems can occur side by side though.

Field-to-field systems are sometimes considered less efficient than "controlled" systems using gated water control structures and secondary or even tertiary water distribution systems and individual field outlets, but this view needs to be qualified. Field-to-field irrigation allows large volumes of water to be applied to fields rapidly in the short time periods that spate floods flow. Conventional water distribution systems based on perennial irrigation practice, with many small field outlets open at the same time, cannot achieve this in spate systems, where water has to be supplied at high flow rates to large areas. Some controlled systems use secondary canals to supply very large plots at high flow rates. However large fields can introduce new inefficiencies. Kahlown and Hamilton (1996), describe plots of 5 ha in four small spate systems in Balochistan. Using a contour map they calculated application efficiency for one of these systems. They computed the relationship between flood flow volume and the distribution of water, assuming that 200 mm of moisture was stored in the root zone. Because the fields are uneven, most of the land is either over irrigated or under irrigated. Taking the current levels of the field they estimated that 1 m of water would need to be applied to achieve 200 mm moisture storage. The rest would be lost to deep percolation, partly for groundwater recharge. Interior bunds could have reduced some of the irrigation inefficiency.

MacDonalds (1989a), qualify assessments of field irrigation efficiency, pointing to research in Pakistan that suggest that some of the moisture stored in deeper layers moves up as temperatures go down in the winter season, typically the maturing stage of spate crops such as sorghum. A similar phenomenon has been suggested in research from Yemen.

The advantages and disadvantages of field-to-field and controlled systems are compared in Table 5.2. The inefficiency of the field-to-field system is particularly related to the difficulty of irrigating downstream fields once cultivation has started on the upstream fields.

Table 5.2 Advantages and disadvantages of field-to-field systems and controlled systems

Field-to-field irrigation	**"Controlled" systems**
No land required for secondary canals, but possible damage to growing crops during second or third irrigations	Land is required for secondary and tertiary canals – though at the end of season canal beds are sometimes cultivated
Smaller floods later in season not diverted because upstream plots cultivated	Large gated flow control and division structures and field off takes with a high flow capacity are needed - expensive
In-field scour on lands result from the breaching of downstream bund	Gated control structures make it possible to divert water at any time in contravention to agreed water rights. This is not usually possible in field to field systems where diversion to fields is achieved using bunds constructed across canals.
Smaller floods do not reach tail end plots	When plots are large, lack of levelling will create uneven irrigation
Timing of breaching can be source of conflict.	Group water supply is not vulnerable to breaking of individual field bunds
Damage of upstream field bunds may jeopardise flows to lower areas – though compulsory maintenance often regulated by local rules/ laws	Sedimentation in canals effects their ability to provide water to the tails

There is a third more rudimentary way of field water distribution; the use of guide bunds. Guide bunds that spread floodwater over a large area. As fields are not bunded they do not allow the water to be impounded and slowly infiltrate. Spate systems with guide bunds are found in the Western Lowlands in Eritrea, where most of the spate irrigation is very recent. Much of the irrigation is on land that was rain-fed earlier, and soils are already well-developed. The guide bund system does not allow soil development or provide a reasonable irrigation efficiency.

Extensification or intensification

A second factor in water distribution strategies is whether irrigation is spread widely or concentrated in a small area. In extensive systems a single irrigation is common, fields may be irrigated twice or thrice prior to cultivation when floods are concentrated on a small area. Local crop varieties are well-adjusted to moisture stress, but even so, there is evidence that at least for some crops the yield produced from two or three irrigations would be greater than two or three times the yield from a larger area irrigated once. Makin (1977), and Williams (1979), suggest this for sorghum in the Tihama in Yemen, and a similar phenomena is reported from Sheeb in Eritrea. In Las Bela in Balochistan if farmers can control floodwater; they will put as many floods as possible onto castor (MacDonald 1987b).

Both types of water distribution pattern can exist in the same system. Makin (1977) describes the use of base flows and small floods to provide several irrigation's near the mountain front in Wadi Rima in Yemen, and the contrasting pattern of a single large irrigation at the tail of the same system. In other cases farmers avoid irrigating their land for a second time, particularly if a crop is established on the land. In Lasbela District in Balochistan, sorghum may be irrigated twice, but if it is mixed with pulses or sesame, farmers say that a second flooding and the subsequent disease damage crops. The same is the case in Sheeb in Eritrea. Once the crops come up, farmers are hesitant to put floodwater on the land, as it would damage the young plants. Similarly later in the season when the crop stands are higher there is the fear that additional irrigation would invite pests and prolong the growing season. Floods that come post-September may be diverted to other areas.

The choice for intensive or extensive system is related to the flood pattern and to the agreed water rights. Concentrating spate supplies on a small area will make it easier to decide where to plough prior to the spate season, with the aim to improve infiltration rates on those fields where irrigation is possible. However some systems are not amenable to intensification. The spate systems in the Suleiman plans and Kacchi plains in Pakistan depend on a single soil bund that is supposed to be broken when the irrigation is over. As long as the bund stands land can be irrigated, but after it is breached there may not be a second chance. Moreover, some smaller spate rivers carry only one substantial flood in a year.

5.2.2 Field water application

It is generally assumed that irrigation application should result in an average of 400 mm net stored in the soil, (Camacho 1987). According to Mu'Allem (1987) the application of 600–1,000 mm of water in a single pre-planting irrigation is sufficient to raise all spate irrigated crops, provided that the moisture holding capacity of the soil is satisfactory. In other areas the preference is for several irrigations. In this case in field-to-field irrigation the bunds surrounding the fields tend to be lower and a single field may be irrigated more than once. In Eritrea, arable fields are flooded using several spates. Fields are flooded to a depth of about 0.5–1 m giving a wetting depth of about

2–2.4 m in the soil profile. According to Tesfai and Stroosnijder (2001) cumulative total of up to 1,000 mm of water soaks into the soil, providing residual moisture for two or sometimes three crop harvests. The fields are flooded to saturation, and some water is lost to deep percolation.

There is a relationship between the height of field bunds and the availability of water. In Wadi Rima, in Yemen locations where crops can expect to receive just one irrigation, the bunds are high and the depth of water application averages 400 mm. In locations closer to the wadi, which can expect two or more irrigations per crop, bunds are lower, and the amount of water absorbed for each irrigation averages 300 mm, (Makin 1977). In the controlled systems with large plots bund heights maybe considerably larger. Bund heights may easily reach two meters, whereas nearer the main channel or hill torrent the height of embankment is higher and even can reach up to 4 m if measured from outer side. High bunds are needed to allow for the large difference in levels across the large plots. The security of irrigation is also very much a function of the strength of the field bunds. To make strong bunds moist soil is compacted and rat proofed. Overflow structures and gates may be used to control the inflows and outflows and to minimise the chance of unplanned breaches. In several spate systems penalties are in place for farmers not maintaining the field bunds as this effects the supply of water to downstream users.

The depth of water that can be impounded in a bunded filed during particular irrigations often affects the choice of crop grown. In Lasbela District in Balochistan, if 300 mm are impounded then guar (cluster bean) alone is sown, mainly as a fodder. If 750–900 mm are stored then castor is sown. Otherwise a mix of sorghum, mung and sesamum/guar is sown. Farmers generally do not aim to achieve depths of over 900 mm. Mustard is only planted when two or more floods can be impounded on the same plot, prior to cultivation, (MacDonald 1987a). In Kachhi District, Balochistan, when there is little floodwater, the land is inspected after the water has receded. If the depth of wetting is insufficient, crops are only sown in depressions or adjacent to unbreached bunds (MacDonald 1987a). In Nal Dat (Balochistan) where the depths of water applied are insufficient to meet the crop water requirements for all crops, rainfall is relied upon to meeting the deficit (Halcrow 1993b). In parts of Bateis command (Wadi Bana, Yemen), farmers apply more than 750 mm of water to cotton, 250 mm more than is required by the crop. Not all this water may be absorbed by the soil – the balance recharging aquifers.

5.2.3 Moisture conservation

As mentioned earlier moisture conservation is as least as important as water supply. Several techniques to conserve soil moisture are seen in spate systems:

- Ploughing prior to irrigation
- Ploughing after irrigation
- Conservation tillage
- Breaking soil crusts.

Breaking the topsoil through ploughing land prior to irrigation greatly increases infiltration rates. Makin (1977), reports that initial infiltration rates for Wadi Rima in Yemen increased from 40–60 mm/hour. Pre-irrigation ploughing also makes cultivation much easier and quicker to carry out once the floodwaters arrive, which is important as a lot of labour is required to cultivate the land after irrigation, (Williams 1979). In the cotton growing coastal spate systems of South Yemen pre-irrigation ploughing used to be mandatory, as it was also assumed to reduce the incidence of cotton pests. This discipline has now disappeared.

There is a strong link between the practice of pre-ploughing irrigation and the reliability of water supplies. In areas where the probability of irrigation is low, it is unlikely that farmers will invest time and effort in soil preparation.

The topsoil should also be ploughed loosely after irrigation or rainfall in order to conserve water, (Williams 1979). However, as the soil is wet, it may not be possible to plough the land for 8–12 days after irrigation, and some moisture will inevitably evaporate, (Makin 1977). The common recommendation is not to delay ploughing for more than two to three weeks, to avoid water loss through evaporation or deep percolation. Extending the post-irrigation period beyond that time may cause a moisture loss in the region of 40 percent. In the Kachhi District in Balochistan, where soils are relatively clayey, fields tend to dry out at the surface. It then becomes important to drill seed deep into the soil. Farmers can only plough fields once and the seedbed is often too cloddy for good, even germination and establishment, (MacDonald 1987a).

Figure 5.6 Ploughing for moisture conservation, Sheeb Eritrea

Small farmers in coastal South Yemen reportedly ‘bury the irrigation’, when the floods come out of season. They plough the land and ensure the topsoil is loose. In some instances they even cover the land with sorghum stalks to further reduce evaporation losses. Figure 5.6 shows post irrigation ploughing for moisture conservation at Sheeb in Eritrea.

A third technique is conservation tillage. In the Sheeb area, Eritrea, this is called “mekemet”. It is practised in the approximately 10-day period between the last flooding and the sowing of seeds. Farmers plough the fields about 0.15 m deep to create a tilth, which conserves the soil moisture by reducing the evaporation losses from the soil surface. At sowing time, the tilth layer is broken down by shallow tillage followed by drilling the seeds in rows, (Tesfai 2001). The same practice is reported from Yemen, where farmers try throughout the growing season keep the topsoil loose to reduce evapotranspiration.

Particularly in areas with silt soils or calcareous soils, soil crusting can be affect water use efficiency and special measures are required. In the Piedmont Plains of the Sulaiman Range in Pakistan, clayey soils, including silty clays, clays and silty clay loams, form a major part of the 'rod kohi' land, (Khan and Rafiq 1990). They are generally more difficult to till and are prone to surface cracking. The soil crust, that develops, reduces the infiltration rate, increases runoff, restricts seedling emergence and reduces crop yield, (Nizami and Akhtar 1990). Appropriate management and agronomic techniques include appropriate tillage practices, surface mulching, increasing the soil organic material (by applying manure and incorporating crop residues, where possible), seeding at appropriate depth, planting on ridges and use of mechanical crust breakers, (Nizami and Akhtar 1990; Tesfai 2001) cited in Tesfai (2001).

Silt soils are also prone to compaction, if they are cultivated when wet with machines. Soil compaction slows down root penetration. Soil water and nutrients become less accessible to the plant and crops on compacted soils will show the effects of drought stress first. In response to this, farmers will re-irrigate their whole field earlier than would otherwise be necessary, thus using water inefficiently. Continuous flood irrigation may also lead to a hard compact layer at a depth of 300 to 400 mm. Clay particles carried in the floodwater are washed down the profile making it difficult for plant roots to reach water, leading to a reduction in productivity. (Mu'Allem 1987) cited in Mu'Allem (1987) suggests that every 2–3 years, the hard pan should be broken up by chiselling using a heavy power unit.

6. Agronomy

6.1 INTRODUCTION

This chapter summarises the agronomic aspects of spate irrigation focussing mostly on traditional systems. Recommendations on improving spate cropping are made in Chapter 12. Compared with other aspects of spate irrigation there is a substantial quantity of literature describing agronomy in spate systems, although much of this is now rather old, see Section 6.12.

In general, spate-irrigation supports low value agriculture, due to the recurrent uncertainties in the timing, number and size of floods that occur and the damage to the irrigation infrastructures caused by large floods. At some locations, in any one year, few if any significant floods occur, which makes cropping impossible. While the risks of crop failure in spate-irrigated agriculture are quite high, the probability of receiving irrigation is not equally distributed throughout the command areas. Within the area served by a wadi, or within a scheme, the area supplied from one off take, there will be lands that have widely varying probabilities of receiving irrigation. This typically would range from very high for fields close to the wadi and supplied from an upstream intake from a wadi that has some seasonal base flow, to very low, possibly only once in every five years, at the downstream margins of schemes. The crops grown and the agronomic practices adopted reflect these variations.

Drought-resistant crops, sorghum, millet, wheat, pulses, oilseeds and cotton dominate the cropping patterns. The production of fodder is also a priority in most spate-irrigated areas in order to support livestock. Livestock provide traction for ploughing and bund building, can be important source of income and also act as a form of saving as animals can be sold to generate cash in bad years.

Farmers have developed various cropping strategies to cope with the risks inherent in spate irrigation:

- In general, they grow local varieties, which are adapted to the local agro-climatic conditions and have a high tolerance to drought.
- They grow crops that will produce some fodder even if the floods fail and grains cannot be grown.
- In some locations they may practise intercropping, when two or three different crops with different water requirements and harvesting times are planted in the same field, so that, in bad years, one of the planted crops can be harvested.
- At other locations crop choice is determined by the timing and volume of the first irrigation and where possible, subsequent irrigations. In Pakistan sorghum is grown in fields with early irrigations, oilseeds and pulses are irrigated later and the last summer floods are reserved for the cultivation of wheat during the winter months. In some cases the selection of crops depends upon soil moisture so is left until after irrigation.

6.2 CROPS GROWN

The selection of the crop and varieties that are grown is affected by:

- Location within the system and the timing and volume of irrigation water that is likely to be received.

- Resistance to drought, pests and disease.
- Yield.
- Use as fodder, particularly in drought periods when grains cannot be grown.
- Suitability for storage.
- Whether crop can be rationed.
- Market and where relevant, support prices.

(Pratt 1977; WS Atkins 1984; Camacho 1987; Wadud & Ahmad 1990; Michael 2000b; van Steenbergen 1997).

The range of crops grown under spate irrigation in Eritrea, Ethiopia, Yemen, Pakistan and Tunisia are listed in Table A3.1 of Annex 3.

Sorghum, millet, wheat, maize and pulses are the main subsistence crops. Farmers will usually only consider growing cash crops (e.g. cotton or sesame) once a food crop has been harvested and their subsistence needs have been met, (Goldsworthy 1975; Makin 1977a; Camacho 1987).

Figure 6.1 Spate irrigated maize, Eritrea

6.3 CROP YIELDS

An indication of the range of yields achieved in spate irrigated areas is given in Table A3.2 in Annex 3. The data indicates that yields vary widely between and within countries and schemes. The conditions necessary to achieve maximum yields are rarely, if ever, found in spate systems. In the spate-irrigated areas of the Shabwah Governorate in Yemen, the average yields are 1,500 to 2,000 kg/ha for sorghum and 1,000 to 1,500 kg/ha for millet. However, the yields of sorghum and millet may rise to 2,500 kg/ha and 2,000 kg/ha respectively in years with good rains and floods, or reduce to 800 kg/ha and 600 kg/ha respectively in dry years, (KIT 2002). The average yields of main crops under spate irrigation in the coastal area of the Red Sea coastal plain and the Aden Gulf are listed in Table 6.1.

Table 6.1 Crop yields in spate irrigated areas of Yemen

Crop	Yields in Coastal Area of Red Sea (kg/ha)[a]	Yields in Coastal Area of Aden Gulf (kg/ha)[a]	Yields in Coastal Area of Southern Yemen (kg/ha)[b]	Yields in Wadi Rima (Red Sea Coast) (kg/ha)[c]	Yields in Wadi Mawr (Red Sea Coast) (kg/ha)[d]
Sorghum	2,000–3,500	700–1,200	900		
White				1,100	1,000
white ratoon				600	
red					600
Millet	–	700–1,200	900	800	600
Cotton	650–1,350			1,100	1,000
extra long staple		850–950	900		
medium staple		1,000–1,600	1,500		
Sesame	700	350–650	500	700	700
Maize	1,100–1,500	–	–	1,400	1,000
Melon	–	7,900–14,100	10,000		5,000–5,500
Groundnut	–	1,200	1,200		–

Data from (a) Al-Shaybani (2003); (b) Mu'Allem (1987); (c) DHV (1979) and (d) Shahin (1990)

In the coastal region of Southern Yemen reasonable yields are obtained for field crops grown under spate irrigation, despite the lack of fertilisers and pest control and without following a crop rotation or improved agronomic practices. The yields of sorghum, millet, sesame and melons fluctuate from year to year due to the planting date, (dependent on the timing of the first irrigation), as well as sensitivity to inadequate watering and attacks by insects and diseases.

Yields vary with location, reflecting the adequacy of irrigation and the effort put in by farmers in moisture conservation and husbandry. This is illustrated in Table 6.2 that shows yields in the traditional Wadi Rima system (before the scheme was modernised) for areas with different probabilities of irrigation.

Table 6.2 Crop yields in areas with different probabilities of receiving irrigation, Yemen

Crop	Perennially[6] Spate- Irrigated Area (kg/ha)	Regularly Spate-Irrigated Area (kg/ha)	Irregularly Spate-Irrigated Area (kg/ha)
Maize	1,200–1,300	1,200	–
Sayf Sorghum: grain fodder	 1,000 3,200	 800–1,000 1,900–2,300	 600 2,000
Sorghum: grain fodder	 1,400 3,500	 400–1,100 1,000–2,800	 0.85 2,200
Sorghum: ratoon grain fodder	 800 2,500	 300–800 1,000–2,500	 200 1,100
Cotton	8,500	850–3,500	350
Millet	–	500–1,000	500
Sesame	–	200–500	200

Data from Makin (1977)

Quite high yields are also obtained on the eastern lowlands of Eritrea. During the 1997–98 cropping season, the average grain yield for sorghum in the Sheeb area was in the range of 1,200–1,500 kg/ha for the main crop, while the (first) ratoon crop had a yield between 700–1,000 kg/ha. Farmers also collect the straw of sorghum, maize and millet from their fields to be used as fodder and for roofing of their dwellings, (Hadera 2001). The water management practice here are to divert as many spate flows as possible on to a relatively small area; ideally farmers hope to achieve two or three irrigations before planting. The result of this strategy is that in a good year harvests in Sheeb can be larger than in most spate system elsewhere in the world - reaching up to 3,500 kg of sorghum on the first cutting and half of that again as a ratoon crop, (van Steenbergen 2003).

Compared with the yields of spate-irrigated crops in Yemen and Eritrea, yields in Balochistan (Pakistan) are significantly lower. Yields in Balochistan are in the range 450–900 kg/ha for wheat, 360–550 kg/ha for sorghum, 200–500 kg/ha for pulses, 360-620 kg/ha for cotton and 150-350 kg/ha for oilseeds, (van Steenbergen 1998). In Toiwar, the average yields for maize and barley are about 740 kg/ha and 1,300 kg/ha respectively, (Halcrow 1998).

The wide ranges in yields observed in spate schemes are variously attributed to the unreliability of irrigation, degree of control that farmers can exercise over uncontrolled spate flows, farming skills and soil moisture practices and crop type, (Goldsworthy 1975; Makin 1977a; Tipton & Kalmbach 1978; WS Atkins 1984; Mu'Allem 1987; Shah 1990; Tesfai 2001; Rehan 2002.) Rural migration can create a shortage of labour at harvest time and the lack of credit facilities, or their inadequacy, can also affect yields, (Shah 1990). A decrease in yield has also been attributed to farmers working in other sectors, because of the unreliability and low returns to labour in agriculture, (WS Atkins 1984).

[6] In this case perennially irrigated refers to lands close to the mountain front that were irrigated with reliable seasonal base flows that could be rotated between fields.

Figure 6.2 A poor under-irrigated sorghum field, Eritrea

It is often suggested that yields could be increased with greater investment in fertilisers, better seed, pesticides and labour. This is discussed further in later sections of this chapter. However, subsistence farmers cannot afford to make substantial investments on inputs if they risk loosing their entire crop in a drought year by changing to higher yielding varieties that are less tolerant of drought and require application of fertilisers. They usually opt for a lower yield and the possibility of growing something in bad years, rather than risk a complete crop failure in drought years.

6.4 CROPPING INTENSITIES

The extent, size and number of floods affect the cropping intensity and change from one year to the next, (MacDonald 1987a). Clearly, as with yields, fertile land situated close to the wadi receiving a reliable supply of water will have higher cropping intensities than areas where there is a shortage of water. This is illustrated in Table A3.4 in Annex 3 that shows cropping intensities are in the range 30–230 percent.

6.5 PLANT CHARACTERISTICS

6.5.1 Planting density

The amount of water plants use depends on the quantity of soil moisture that is available and accessible to them, the root-growth rate and extent of root development. The farmer can influence the relationship between these factors by adjusting the planting density on the plot of land according to whether or not further rain or floodwater in the growing season is likely, (Williams 1979).

In some areas crops are planted at wide spacing to provide each plant with a large volume of soil moisture, (Verheijen 2003). In others crops are planted at quite high planting densities. For example in Eritrea farmers plant at high density as:

- Densely grown crop can be thinned and used to feed their animals that do not have any other source of feed.
- Water logging and infestations of insects like locust and heavy attack by birds can kill young pants. These problems reduce the plant population as well as the yield. To cope with such problems high density planting is preferred.
- Densely grown plants suppress weeds. The majority of the farmers do not practice weeding, (Ogbamichael, 2004).

A very dense plant population creates a high competition among the plants for moisture, nutrients and light. As a result of this competition, plants, especially sorghum, grow very thin and tall and the yield is low. Young crop stands of high plant density are more affected by drought than equal stands of lower density. Williams (1979) suggests that in order to use water more efficiently in spate irrigation, it may be more suitable to grow cultivars that yield more grain per plant and grow them at a lower plant density. This may produce more grains, but may not be acceptable to farmers for the reasons listed above.

6.5.2 Traditional versus improved varieties of crops

Local cultivars are well adapted to their environment, having developed over thousands of seasons; selection has been both natural (climatic) and man-made. Where water supply is limited, a local cultivar can produce some grain and fodder – and if additional rainfall or floodwater becomes available, the yield increases, (Williams 1979). Ratooning is more appropriate with local varieties than improved ones, (Michael 2000a).

In the Yemen, local varieties of sorghum and millet have less above ground growth than improved varieties and can tolerate extremely dry conditions by regulating their water use through surface area. There is some evidence to suggest that local cultivars have slightly faster, deeper-growing root systems than improved cultivars so they can exploit moisture held deep in the soil profile (Williams 1979).

Improved varieties are rarely used in Kachhi District, Balochistan and they have no advantage over local cultivars, (MacDonald 1987a). Farmers in the Chandia spate irrigation system in Balochistan report that improved varieties are unavailable or difficult to obtain (Halcrow 1993a).

It is widely recognised that research into improved varieties for spate irrigation is needed. In D.I. Khan in Pakistan some developments have already been made:

- Early maturing sorghum varieties have been made available to farmers and these give higher yields than local varieties.
- Higher-yielding varieties of bajra have been developed, which are not damaged by birds and which grow better in hot and dry conditions.
- A gram variety has been developed which is blight tolerant, (Khan A B 1990).

Finally, Michael (2000b) emphasises that even though the main focus on research farms is often on improving crop yield per unit area, the availability and sustainability of a variety are also crucial. Local cultivars still fare well in terms of drought resistance, labour inputs, market values, food values and storage, but these factors are rarely given sufficient consideration.

6.5.3 Plant rooting depth

Crops grown under spate irrigation need to have deep rooting depths in order to exploit all the available moisture stored in the soil profile. Sorghum and millet can root to about 3 m and cotton to over 3.5 m and are therefore well suited to spate irrigation, (Williams 1979). Maize is less suited to spate irrigation when only one irrigation can be applied, as roots rarely grow more than 1 m and cannot reach soil moisture stored deeper in the soil profile.

6.5.4 Fertilisers

In most spate-irrigated areas, there is minimal use of artificial fertilisers, (Goldsworthy 1975; Tipton & Kalmbach 1978; WS Atkins 1984; Shah 1990; Halcrow 1993b; Michael 2000a; Tesfai & Stroosnijder 2001) or organic fertilisers such as manure, (MacDonald 1987a; Halcrow 1998; Michael 2000a; Tesfai & Stroosnijder 2001). Farmyard manure is used in some areas of Balochistan (Pakistan) where soils are sandy and recognised as being relatively unfertile, (MacDonald 1987b).

It is often suggested that yields could be increased with greater investment in fertilisers, better seed, pesticides and labour, (Tipton & Kalmbach 1978; Mu'Allem 1987; Khan A B 1990; Shah 1990). Agro-economic studies have shown that yields might be increased by 30–75 percent with the addition of these inputs. Table A3.3 in Annex 3 that shows yield responses of spate irrigated crops to nitrogen fertiliser and improved cultural practices in the coastal region of Yemen. In Balochistan, adding fertiliser increases the productivity of certain local varieties of crop, (Khan M 1990). However, improved varieties, that respond to a higher level of inputs, can only reach their potential if irrigation is adequate, (Goldsworthy 1975; Williams 1979). Local cultivars are more adapted to water shortage than improved varieties.

It is important to note that the use of fertilisers on traditional cultivars does not always lead to increased crop yields. In Wadi Rima, Yemen, the yields of traditional varieties of crops tended not to respond to input of fertilisers, manure and pesticides, (Goldsworthy 1975). More regular irrigation may be needed where fertilisers have been applied – their use is not necessarily suitable for areas receiving irregular spate flows.

Most spate irrigators believe that their soils are naturally fertilised by the fine sediments that are deposited during flood irrigation. Floods in spate rivers often carry around 10 percent by weight of fine silts that are deposited on the fields[7]. Silts are usually rich in plant nutrients and possibly nitrates, (WS Atkins 1984; Shah 1990; Tesfai 2001). Mu'Allem (1987) reports that a 1 m depth of irrigation with heavily silted water spread over 1 ha contains 0.92 kg nitrogen, 0.01 kg phosphate and 11.02 kg potash. However the origin of floodwater affects its nutrient value. In the Sheeb area (Eritrea), when spate flows come from nearby hills and mountains, which have little vegetation cover, the sediment is poor in nutrients. Runoff from the highlands, where land is used for agriculture, contains organic matter and plant nutrients. Although soils in Sheeb received inputs of total N, P and K from spate flows, soils are in fact low in N and organic matter. The application of organic fertilisers would increase the organic matter

[7] Gilani (1990), reports that the floodwater in D. I. Khan in Pakistan contain an incredible 35–40 percent silt.

content of the soil and improve the water storage and nutrient retention capacity of the soils, (Tesfai 2001).

Other factors related to the limited use of chemical fertilisers are:

- Expense, their use depends on the availability of credit to farmers.
- The lack of information on the use of fertilisers and pesticides.
- Availability.
- Timing of application – if applied before flooding fertilisers will be washed off by irrigation.

In the Sheeb area (Eritrea), farmers believe that mineral fertilisers and manure will burn the crops, (Tesfai 2001). However, Tesfai states that if manure is broadcast after irrigation has finished and before the seeds are sown, fertilisers will be retained in the soil – and manure will decompose and dissolve, so that germinating seeds do not get burnt.

In the Yemen applying nitrogen fertiliser after or during flood irrigation gave "moderate to good" results when cotton or other crops had received a moderate irrigation, but were negligible where irrigation was light or heavy. With a heavy irrigation, it is thought that greater evaporation from the soil surface after irrigation may draw nitrogen away from the roots. The best results were obtained where urea or calcium nitrate was applied to cotton before flooding. It was felt that neither phosphate nor potash was needed in areas where irrigation has been practised for some time (Mu'Allem 1987).

The issue of fertiliser usage in spate irrigation has yet to be resolved. Much of the literature on this topic comes from the 1970s and 1980s when large investments in spate irrigation were being made in Yemen and Pakistan and tend to be biased towards the larger spate systems where there was some agricultural extension support to farmers. More site specific studies, carried out in small farmer systems rather than the controlled environments found in research farms, are needed to develop clear guidance on cost, benefits and attractiveness to farmers of the use of increased inputs in spate cropping.

6.6 SEEDS

Farmers in spate irrigation systems mainly use local varieties, which are adapted to the local agro-climatic conditions. Seed is normally retained from one year to the next. The practice of using self-produced seed can lead to diseases. However, there are very few substitutes for the traditional varieties as agricultural research in most countries has been concentrated on improving the yields of perennially irrigated crops. Seed may be purchased in some instances when self-produced seed becomes liable to disease, (Halcrow 1993a and b; Goldsworthy 1975; MacDonald 1987a and b).

6.7 PESTS, DISEASES AND WEEDS

As the cropping pattern in many spate irrigation systems is dominated by monocultures and large areas are planted at the same time, the impact of pests and diseases can be dramatic. The use of pesticides and insecticides is rare as most farmers lack the financial resources to apply these products. Following a number of insect attacks, which affected the quality and quantity of the crops, several types of crops were not cultivated by the farmers in the Sheeb area (Eritrea) during the 2000–2001 cropping season, (Kahsaye 2002). In Wadi Rima in Yemen, the late sowing of crops, especially of maize and cotton, was reported to exacerbate the problem by carrying over insect pests. However, planting times depend on the timing of irrigation and are often far from optional for pest control. Where it is possible changing of sowing dates is one of the control measures used to cope with outbreaks of pests and plunder by birds, (Tesfai 2001).

6.8 CROPPING PATTERNS

Examples of the cropping patterns adopted in spate irrigated areas of Yemen Pakistan and Eritrea are shown in Table A3.5 of Annex 3.

There is a tendency for cultivation of traditional spate-irrigated crops to be in decline. In Pakistan and Yemen, traditional cereal crops, such as sorghum and millet, cannot compete with imported wheat, which is sold at low subsidised prices in the local markets. With increasing prosperity and urbanisation, changing taste may lead to deterioration in the position of the local producer compared with that of the importer. Rising standards of living and changing habits can reduce the market for traditional grains, such as sorghum, allowing imported wheat and other cereals to take their place, (Makin 1977). Consumers in Yemen prefer wheat as the consumption of traditional food grains has a low socio-economic status. Furthermore, governments have promoted the cultivation of modern cash crops at the expense of traditional spate-irrigated crops by directing their research, extension and credit services to high value crops and promoting the use of groundwater for irrigation. The cropping patterns in Wadi Tuban and Wadi Zabid in Yemen have changed dramatically, due to the remarkable increase of shallow wells since the 1980s. As a result, the area under banana has increased from 20 ha in 1980 to more than 3,500 ha in 2000 in Wadi Zabid, while about 2,300 ha are under vegetables in Wadi Tuban.

Figure 6.3 Bananas irrigated from spate flows and shallow groundwater, Wadi Zabid, Yemen

Cropping patterns in traditional spate irrigated areas are strongly influenced by the priority given to subsistence crops, the need to grow forage to support livestock and the strategies that farmers adopt if there is insufficient water, see Box 6.1. The latter include growing fodder as the main crop, growing alternative crops depending on soil water status following irrigation, diversifying crops, leaving land fallow if there is insufficient water and intercropping fodder crops with pulses. In Balochistan, farmers at the head of the system, who normally receive a more reliable supply, can follow a cropping pattern of mixed sorghum, mung beans-wheat. As water becomes less reliable at the middle and tail end sections of the system the cropping pattern changes. If the flood season arrives late, moisture is stored in the soil and wheat is grown. If the flood season is early, sorghum is grown and later floods are used for oilseeds, (van Steenbergen 1997).

Iqbal (1990) proposes an alternative system of raising trees, agricultural crops and livestock simultaneously in the Rod-Kohi (spate irrigated) area of D. I. Khan in Pakistan, where farmers can expect to have only one good crop once in every five years. Growing babul trees is expected to increase soil fertility as the trees fix biological nitrogen. As well as improving soil fertility, the wood can be used as fuel as there is a high demand for firewood in the area, to replace cow dung. The dung could be used as a fertiliser, leading to better yields. However, the author acknowledges that further research is needed into the viability of arboriculture in spate irrigated areas.

Tesfai (2001) also refers to the potential of growing trees along field bunds. Trees can be used as a source of fodder and to improve soil fertility through nitrogen fixation and provide crops with some shelter. Trees also prevent nutrients from leaching during flooding and pump up nutrients from the soil which are inaccessible to crop roots.

6.9 CROP ROTATION

"No real crop rotation is practised in the Wadi Rima. As a result of continued monoculture soil fertility is declining, yields [are] decreasing and plant pests and diseases [are] multiplying. There is no leguminous crop in the rotation which by nitrogen fixation could build up fertility for the succeeding crop."
(Goldsworthy 1975, p.24)

In many areas crop rotation is not practised and in others farmers may be unaware of its benefits. Where practised crop rotations may be relatively simple, e.g. in Chandia, Balochistan, the crop rotation is sorghum, fallow, oilseed and sorghum. However, in most areas, with increasing population pressure and the pressing need to grow subsistence crops improving rotational practice is not seen as a priority by farmers, (Makin 1977; Halcrow 1993a; Shah 1990; Halcrow 1993a).

6.10 RATOONING

Sorghum ratooning provides a high return on investment. In the Sheeb area (Eritrea), when there is sufficient floodwater, sorghum can produce a main crop, a first ratoon crop with grain yield and a second ratoon with forage only, without the application of any fertilisers (Tesfai 2001). When the main crop has matured, the remaining moisture in the soil profile is deep and, unlike new seedlings, a ratoon crop is able to extract this moisture. Ratooning also saves on material and labour, as land does not require preparation or sowing and there are no seedlings to tend. The length of time between sprouting and harvesting is always shorter (70–80 days) in a ratoon crop than in a seeded crop, (Halcrow 1993a; Tesfai 2001).

6.11 LIVESTOCK

The importance of livestock in the livelihood strategies of spate irrigators is discussed in Chapter 3. In most areas, livestock is an integral component of the livelihoods of spate irrigating households. Its importance is related to the reliability of cropping and reduces when the probability of irrigation is relatively high, or if there are local opportunities to generate an income outside the agricultural sector.

The need to produce fodder for livestock is usually second only to the need to produce grains for consumption. Production of fodder thus has a high priority in the selection of the crops that are grown and in some areas it can be a cash crop.

Figure 6.4 Marketing green sorghum as fodder – Yemen

In Lasbela District (Balochistan) crops grown as fodder include sorghum straw, green sorghum, mung and guar haulm and green guar. Only where areas are irrigated regularly by spate floods, or where grazing land is irrigated by spates, can cattle be provided with enough fodder. The number of cattle kept by farmers is proportionate to the amount of fodder/forage available, i.e. where fodder/forage production is low there are fewer cattle, (MacDonald 1987b; Makin 1977).

The Sheeb area in Eritrea provides a good example of the importance of livestock to spate irrigators. A typical farm household in the Sheeb area has two dairy cattle and two draught animals. The main animals kept include oxen, cows, camels, goats, sheep, donkeys and chickens. Each animal has its own place within the farming system. Cows, goats, sheep and chickens provide a source of food and income. Camels and donkeys are used for transporting the crop produce and crop residues to homesteads or markets as well as for transporting people Oxen are used for constructing and maintaining the temporary diversion structures and field embankments and to till the land. Donkeys are used for fetching water and transport. Livestock products, mainly milk, butter, meat and eggs, serve as a buffer against low crop yields during the years of drought

6.12 AGRICULTURAL EXTENSION, TRAINING AND RESEARCH

Generally, agricultural extension in spate irrigated areas is poor, many regions lack a resident extension service supporting spate irrigators. Elsewhere the resources of the agricultural research and extension services do not meet spate farmers development needs (Khan A B 1990; DHV 1988). Van Steenburgen (2003) reports that in Pakistan the spate irrigated areas lie in the most marginalised and socially low-ranking districts. This is reflected in the decision making and resource allocation for irrigation sector at the national level. The bulk of investment in agricultural research and physical development has gone into perennial canal irrigated agriculture. Spate irrigation is not the part of agriculture or engineering curriculum in any formal educational institution of the country. A lack of academic knowledge and the lack of empathy among decision-makers for the marginalised communities that practice spate irrigation has negatively affected state support for extension, training and research. The spate irrigated sector accounts for about 1.5–2.0 million ha and has potential to reconcile food security with natural resource management (ICARDA 1998).

Tesfai (2001) reports that staff working on local systems in Eritrea may lack knowledge and experience, particularly of soil and water management in spate systems, (Tesfai 2001).

The literature suggests that research into the wide range of topics listed in Table 6.3 is needed to increase yields and the returns from spate irrigated agriculture.

Table 6.3 Research topics

Drought resistant new crops and varieties of existing crops	On-farm water management (including depth of water retained)
Propagation of seedlings	Land preparation before flooding
Times of sowing	Moisture conservation through mulching or deep tillage
Crop spacing and plant density	Farm mechanisation
Crop spacing and plant density	Harvesting methods
Crop rotations	Crop storage
Fertiliser applications and weed and pest control	Field levelling
Improving animal nutrition	Soil erosion and soil conservation

(Goldsworthy 1975; Makin 1977a; Williams 1979; WS Atkins 1984; MacDonald 1987a and b; DHV 1988; Khan A B 1990; Michael 2000b; Rehan 2002)

It is important to improve the link between research and extension, (Michael 2000b). Where possible research needs to be carried out with farmers, in farmer led trials and experiments on working spate systems and farmer to farmer demonstration activities so as to get away from the “research farm” approach.

Other practical measures that need to be considered include:

- Establishment of seed banks (Michael 2000b).
- Documentation of indigenous pest management practices (Michael 2000b).
- Integration of indigenous technical knowledge with scientific knowledge to increase productivity and system sustainability (Tesfai 2001).
- Improve existing mixed/inter-cropping systems (Khan M 1990).

- Improving sharecropping arrangements (DHV 1988).
- Land distribution practices (Michael 2000a).

Box 6.1 Timing and volume of irrigation and cropping patterns – An example from Sheeb, Eritrea

The cropping system is flexible and largely determined by the amount of floodwater and rainfall received, which vary widely from year to year. Crop failures due to a shortage of water are common; thus the farmers have developed a cropping system to minimise crop failures.

At the beginning of a cropping season, a late maturing crop is planted. If this crop fails due to over flooding or shortage of water or insect attack, it is replaced by early maturing variety or by a different type of crop. If crop failure is repeated a number of times, a drought tolerant sorghum variety like Durra is planted mainly for the production of animal feed for their livestock but not for crop production.

The most common cropping system followed is to plant sorghum as the first crop, followed by maize and then watermelon is planted as a third crop. Due to droughts in recent years it has become difficult to plant maize, because of drought as enough rainfall is not received to allow good germination of the crop. These days, the main crop of sorghum is followed by its first and sometimes by the second ratoon. The growing of a second crop of maize has been stopped except in areas where maize is planted as the first crop. In the southern parts of the eastern lowlands where the evaporation rate is very high and the annual rainfall is very low only one crop of maize is planted each year.

Adapted from Ogbamichael (2004)

7. Water rights and water distribution rules

7.1 MANAGING UNPREDICTABILITY

Water distribution rules and rights help to mitigate the unpredictability that is inherent in spate irrigation. Rules and rights impose a pattern and reduce the risk of conflict, by regulating relations between land users that have access to floodwaters. The way rights are defined in spate systems is different from perennial systems. In essence water rights in spate systems are reactive. They deal with agreed claims in a changing and variable environment. They describe acceptable practices in a given situation, rather than quantifiable entitlements to a resource, as in perennial systems.

Water rights and water distribution rules in spate irrigation regulate access to water and hence minimise conflict. Water distribution rules make it easier to predict which land will be irrigated. As such they encourage land preparation by pre-flooding, which is important for adequate water storage and moisture conservation, (see also Chapter 5). Water rights and water distribution rules also define the likelihood of irrigation for different areas and hence serve as the key to the collective maintenance and rebuilding of diversion infrastructure. In particular where floodwater users depend on one another for maintaining flood canals and reconstructing diversion structures and if this work is substantial, agreement on how water is distributed is a precondition for co-operation. However, water distribution rules are not necessarily finely detailed. Serjeant (1980) makes this point for instance for Wadi Rima, Yemen – noting that 'many of the disputes seem to lie dormant, though not forgotten, … they can spring to vigorous life with some new turn of circumstances'. Al-Maktari (1983) makes a similar observation for the unwritten customary rules in Wadi Surdud.

Water distribution rules also have to be placed in the context of medium and long term change in flood irrigation systems. Increases in land levels and changes in wadi courses and flood canals are almost unavoidable. Spate irrigation systems are morphologically far more dynamic than perennial irrigation systems. Water distribution rules deal both with reducing and mitigating the risk of such dramatic long-term changes, as well as coping with them when they come along. In the end water distribution rules tend to be packages describing the distribution of flood water, the way maintenance is organised, the practices in avoiding breaches and changes to the command areas and the arrangements and penalties, associated with operating the rules. Table 7.1 summarizes one such set of rules for the Kanwanh spate river (Rod-e-Kanwanh) in Dera Ghazi Khan District in Pakistan. The rules were recorded during a land settlement of 1918/1919 and are still used.

The remainder of this chapter describes the most common types of water distribution rules, including the rules on protecting command area boundaries (Section 7.2). Section 7.3 describes how the water distribution rules are enforced. There is a strong relation with the overall governance in an area and the local organisation in spate irrigation and the codification of the water distribution rules in particular. The final Section 7.4 describes how changes in the water distribution are caused and how they take effect. Several recent engineered interventions in large spate schemes have unwittingly altered water distribution rules, by creating new opportunities for different players. The reactive nature of water distribution rules in spate system has often led to a gradual accommodation of these new opportunities. The purpose of this chapter is to increase awareness and understanding of water rights and the changes therein, so as to:

- Support the development of water distribution rules in new systems.
- Understand the process of codifying and enforcing water rules and rights and identify opportunities for improvement in enforcement and modification of water rights.
- Understand the impact of interventions on existing water distribution rules and practices and avoid the worst of pitfalls.

Table 7.1 Water management rules in Rod-e-Kanwah (Kot Qaisrani, DG Khan, Pakistan)

Water distribution	**Command area protection**
Water distribution starts from the head and goes to the tail	Even if fields remain barren for long periods the right to irrigation remains valid.
When after a first irrigation the upstream fields are watered, but the downstream fields are not irrigated sufficiently, then the upstream field can still take precedence in using the second flow.	The location of a diversion structure, channel intake or division structure can be changed with mutual consent of landowners.
There is no limit on depth of irrigation of an upstream field.	If after filling his own field a land owner delays breaching his diversion structure and a nearby field is destroyed, then the losses will be met from the person who did not breach the diversion structure in time.
No body can sell or donate his share of water. In land transactions water is transferred as well	No person has a right to construct new branch/flood canal that deviates from the prevailing situation. However, when the channel has changed naturally, then a new flood canal can be constructed, provided the earlier flood canal is completely damaged.
A field cannot be supplied by more than one diversion structure	When a person intentionally destroys the water course/diversion then loss is recovered both for the loss of water and the destruction of the adjacent field(s).
If a bund in a flood channel irrigates two fields, water will first be applied to the higher land.	On reappearance of eroded land, (through siltation) the rights are vested with the original owner.
When a diversion structure has been washed away during irrigation, it is allowed to construct a new diversion even if water is already reaching other fields.	
Maintenance	**Others**
Common maintenance work is performed on the basis of area of land	Ownership of the flood channel – including trees within the channel is based on ownership of the adjacent fields.
To maintain the flood embankments close to a main bund is the responsibility of all users of the ghanda (diversion bund)	A diversion structure can be constructed on one's own land as well as others land, wherever it is most suitable.
Strengthening the banks of flood canals is the responsibility of the owner of the land facing the Wadi bank.	Nobody can expand his land by encroaching upon the river bed.
Landowners whose fields are irrigated through overflow (chal) and not through bunds and embankments do not take part in the common maintenance work.	When a shareholder does not contribute his labour during the specific period, he will not get a right to water in the current year. If he wants to contribute in future then he will have to compensate the previous year costs of common labour and also provide eight days labour as a fine.

7.2 RULES AND RIGHTS

There are several types of rules that regulate the distribution of the varying quantities of flood water. Not all rules apply in every system, but it is usual to find that several rules are used simultaneously. The repertoire of water distribution rules includes:

- Demarcation of land entitled to irrigation
- Rules on breaking diversion bunds
- Proportion of the flow going to different flood channels and fields
- Sequence in which the different fields along a flood channel are watered
- The depth of irrigation that each field is to receive
- Practices regarding second and third water turns
- Rules on small and big floods.

In addition there are rules that regulate changes in the command area and system morphology:

- Rules on maintenance of bunds and boundaries
- Rules on adjusting the location of intakes and other structures
- Rules on manipulating wadi bed and flood canal scour and siltation processes
- Compensation for lost land.

7.2.1 Water distribution rules

Rules on land demarcation

Demarcation rules define the area entitled to irrigation. As such, these rules precede all other water distribution rules. They define the command area and with this the land users with access to the spate flows. Demarcation rules often protect the prior rights of downstream landowners, by prohibiting new land development upstream which could result in the diversion of floodwater to new lands, formation of a new group of stakeholders and the loss of farming systems and other established water uses downstream. This can result in violent conflicts, particularly in areas where irrigation development is relatively new. For example in southern Ethiopia land alongside the Woito River was given to private investors. They diverted water upstream to the detriment of nomadic groups downstream, whose only option had been to use excess flood water in the summer season. In the conflict that ensued workers of private investors were killed. A history of long running water rights disputes in Wadi Rima Yemen related to the construction of “illegal” upstream canals is described later in this chapter.

The demarcation of the outer boundaries also ensures that overspill from breaches in flood channels does not develop into an established practice, (van Steenbergen 1997). The corollary of such demarcation rules are the penalties for negligence in the maintenance of bunds and channels. In the spate systems of the Suleiman range in Pakistan explicit agreements exist, obliging landowners to plug gullies that developed after severe floods. This is to prevent new drainage patterns developing in these soft alluvial plains. Similarly, in Eritrea and South Yemen farmers are penalized for not maintaining field bunds which could cause water to escape to new areas. Such rules are, however, not in force everywhere.

In some systems there are ‘sanctioned’ overspill areas. Though they do not have a recognised claim to the spate flows, custom has it that these areas receive water during unusual high floods. Water is then allowed to escape at certain pre-arranged points to avoid damaging the canal network downstream.

Like most of the other distribution procedures demarcation rules are in place when water is scarce. They are more common in lowland systems, where land is abundant, than in highland systems. Ahmad *et al* (1998) documents the ongoing land formation in four small upland systems in Balochistan (Pakistan).

Rules on the breaking of bunds and timing of water rights

A category of rules closely related to the rules on the boundary of the spate area concerns the breaking of diversion structures, or the timing of a water right. The rules on breaking bunds are usually in place in areas where the entire river bed is blocked by earthen bunds, as in the lowland systems in Pakistan. The earthen bunds are generally made in such a way that they scour out in high floods. This works as a safety valve (see also Chapter 10). It avoids substantial damage to the canal network, as very large floods flow down the river rather than damaging canals and fields. In several systems there are also rules on when farmers can break bunds, e.g. once the designated area served by an upstream bund is irrigated (see above) or when a certain time-slot of the flood season has lapsed. Examples of such time-slots are the rules for breaking gandas (earthen bunds) in the Nari River in Kacchi, Pakistan (Box 7.1). The rules were formalised in 1917 and are still observed, although there is considerable tension on the actual breaking of bunds.

Box 7.1 Rules on Nari System, in Balochistan Pakistan prepared in 1917 on revision of older rules and still observed

- From 10 May to 15 August the landowners of the Upper Nari are allowed to make gandas (earthen bunds) in the Nari River.
- When the land served by one ganda in Upper Nari is fully irrigated, the landowners in that ganda must allow landowners of the next ganda to break it.
- After 15 August the landowners of Lower Nari are allowed to make gandas in the Nari River.
- Landowners in Upper Nari are not allowed to irrigate their land during this period or let the water go to waste.
- Water is not allowed to go to waste to the low lying areas east and west of the Nari River. Guide bunds will prevent water flowing to these areas – all landowners will contribute towards these bunds with farmers in Lower Nari paying twice the amount per hectare in case bunds on the Upper Nari are broken.
- If any dispute arises judges appointed by Kalat State will inspect the area and are authorised to decide whether a downstream party should be allowed to break the ganda at an appropriate time or whether a guide bund should be repaired within 5-10 days. If repairs to guide bunds are not made the main bund of the area concerned may be broken.
- In case a landowner refuses to contribute gham (the contribution for maintenance) his land may be confiscated.

The reluctance of upstream land users to have their bund broken is not only because it allows more water to be diverted to the upstream area, but also because it saves the effort of rebuilding the bund in a subsequent year, see Box 7.2.

Box 7.2 Disputes over bund breaking

A fairly typical example of a dispute on the breaking of a soil bund concerns the Chacar Bund on the Chakar River in Balochistan. In the past this earthen bund – spanning some 50 m across the river – was constructed using bullocks and tractors. It collapsed every year, as the water seeping through its base undermined the structure. However, in 1990 the landowners of Chacar were given a generous allocation of bulldozer time by the government. They utilised this by making a very strong bund. The bund did not fail that year. It irrigated all demarcated land of Chacar and then the Chacar landowners allowed the water to escape through a breach in their flood channel to an area that was not entitled to floodwater. The same pattern repeated itself in the subsequent year. The Chacar landowners were not keen on breaking their bund, as they wanted to spare themselves the effort of rebuilding it. This led to fierce protest from downstream landowners, who approached the head of the district administration. The downstream landowners argued that the head of the district administration should break the controversial soil bund. However, his verdict was only partly a success for the complainants. He reasoned he could not break the bund since there was no earlier agreement on breaking bunds in the Chakar River. However, he did maintain the demarcation rules and ordered the Chakar farmers to repair the breach in the flood channel to prevent water from going to unauthorised channels.

Rules based on the time slots when water diversion is allowed in different parts of the system are also found in Yemen. An example from Wadi Zabid is shown in Box 7.3.

Rules on flow division

This category of rules arranges the distribution of water between the different flood channels. Where an area is served by several flood channels, there may be an agreement on the proportion of floodwater going into the different channels. In practice, this is usually achieved by using rather crude hydraulic structures, e.g. the head sections of flood canals may be different widths and obstructions may be placed in front of some of the channels to achieve the required division. Flow division may also be practised along a flood channel, with the width of the field intakes determining the proportion of flow that each field receives.

Figure 7.1 Flow division in a flood canal, Yandafaro, Ethiopia

Box 7.3 Water distribution in Wadi Zabid

The traditional canals in the Wadi Zabid system were split into three groups with water rights at different times of the year. These rules were retained when the system was modernised in the 1980s.

The canal groups and the periods when they have water rights are:

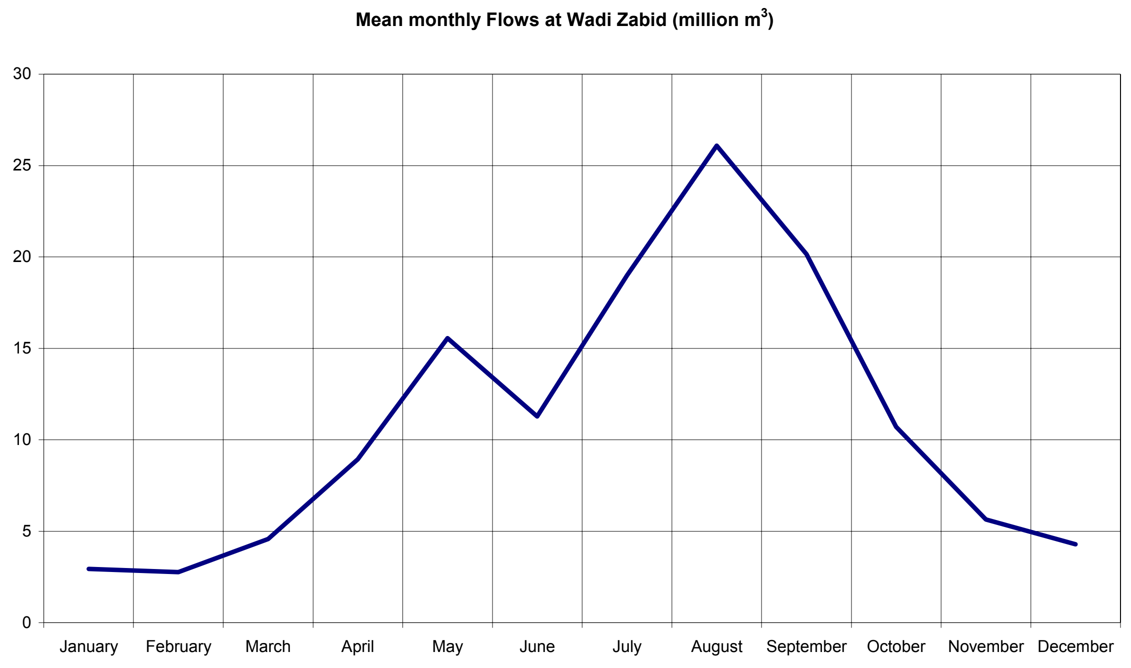
Group	Nominal Command area (ha)	Dates
Group 1 (Upstream canals)	4,325	29 March to 2 August
Group 2 (Middle canals)	9,165	3 August to 13 September
Group 3 (downstream canals)	1,305	14 September to 18 October

Canals within the groups also have water rights at different periods within the group turns.

This allocation gives the upstream canals access to base flows and the first part of the main flood season. The middle reach canals (group 2) have about six weeks during the period when the main flood season occurs to irrigate the largest area. The downstream canals have a shorter period at the end of the main flood season.

Mean monthly flows measured upstream some distance from the first canal off take are shown below. Some water is lost in minor abstractions and bed seepage between the measuring location and the first canal off-take and little flow reaches the first diversion structure outside the period of the water rights.

Box 7.3 Water distribution in Wadi Zabid (continued)



Flow divisions within the flood channels may be fixed, but it is more common that there is a large degree of flexibility to adjust to changing bed levels of river and flood canals and to variations in the flow. An example of a flexible flow division is the traditional main division in the flood canal of Wadi Laba in Eritrea, which used to be adjusted by moving brushwood around. During a spate the water masters of the five main flood channels stood on top of the structure and adjusted it to ensure that the flows to each area were fair, taking into account earlier irrigation. In the same system a series of gabion command area flow division structures were constructed to distribute water between major command area channels and to stabilize the canal beds. The first designs were conventional, but later a more flexible structure was developed at the instigation of farmer leaders. It consists of a curved wall that provides a strong point splitting high flows. Lower flows are adjusted using small earthen bunds to control the proportion of flows diverted to the two main channels. (This structure is shown in Figure 10.27 in Chapter 10).

In Balochistan (Pakistan) flow divisions are affected by canal bed and water levels and slopes, it is unusual to find rules in this area. Conflicts due to changing canal bed levels, after fertile fine sediment deposits were taken from the channels, are reported in Ahmad *et al* (1998).

Many flow divisions occur automatically when the flows are not too large. When the quantity of water is small it is diverted to one part of the command area only and the other flood canals are blocked, usually with a small earthen bund. When flood flows are large however water will break the small bunds and flow to several channels simultaneously.

Rules on sequence

A fourth category of rules is the pre-arranged sequence in which fields are irrigated. Where it applies, the route that water follows within the area entitled to irrigation is described in detail, in terms of the branch channel which will receive water first and the priorities of the different fields within the branch channels. Irrigation in many cases moves from the head of the channel to the tail (Serjeant, 1964; Maktari, 1971). In Yemen, the fundamental rule governing the use of spate water for irrigation purposes grants upstream users priority rights to irrigate their fields, but downstream users may not be denied the right to surplus water after the upstream users have exercised their rights to divert a quantity of water sufficient to satisfy their needs. Sequence rules are called 'numberwar' or 'saroba paina' (Pakistan) or 'ala'ala fala'ala or rada'ah' (Yemen).

The sequence is adjusted according to the level the flood reaches. If the flood is low, the water will only flow in one or two of the priority branch channels and the sequence rules will apply to those channels only. But, if the flood brings large quantities of water, it will find its way through a large number of channels simultaneously. Moreover, during high floods the force of water is larger and instead of being controlled and regulated, it will flow in a large number of fields at the same time.

In some cases the head reach first principles does not apply. One example is the Chandia system in Balochistan (Pakistan), where the upstream area is only supplied at high water levels or after the downstream area is irrigated. In other systems there are rules to send larger floods downstream on a priority basis.

Figure 7.2 Spate-irrigated Fields in Wadi Tuban, Yemen

Rules on depth of irrigation

All the four rules impose a certain predictability and equity. The definition of the command areas, rules on breaking diversion bunds and specific periods with water rights and the limitations on the width of field intakes prevent the water from being monopolised in the head reaches of the flood irrigation system. The sequence rules identify priority areas. Equity issues are also significant in the fifth type of water distribution rule, which concerns the depth of irrigation and is expressed in agreements on the height of the field bunds. These field bunds are usually built up from the sediments deposited within the fields. The height of the bunds determines the amount of floodwater that can be stored in the fields.

Rules on the height of the bund and hence irrigation depth are not common in spate areas in Pakistan. They seem to be standard practice in Yemen and appear to be based on a ruling of the Prophet Muhammad. The amount of flood flow to be applied to a field with palm trees shall be the depth of two ankles or an amount sufficient to reach the tree trunk. According to the 11-century Islamic jurist Al-Mawardi, the underlying principle of this ruling is that the amount of water applied shall be sufficient to water the crop and that it is easy to measure (Varisco 1983). The prevalence of irrigation depth rules in Yemen is probably related to the practice of field to field irrigation. In this system a farmer gets his turn as soon as his neighbour has completed irrigation his land. This is done by cutting the bund surrounding the field of the upstream farmer. Competition between neighbours can be fierce and rules on water depth may have evolved to mitigate this. Moreover, if the bund in the neighbouring field is very high and too much water is impounded, uncontrolled breaching could cause severe damage to the neighbouring fields. In some of the small mountain systems in Balochistan rules are in place that prescribe that the soil for repairing these field boundaries will be taken from the lower plot (Ahmad *et al* 1998).

In contrast, when each field is fed by its own separate intake, as is usual in the spate irrigation systems in Pakistan, such conflicts are rare and rules on the depth of inundation are unusual. The amount of water applied depends on the height of the field bund and the levelling (or lack of it). Yet in most systems there is no limitation in this respect. Field bunds are seen as a way of disposing of the excess silt that accumulates with the floodwater and can reach any height.

In general it appears that the height of field bunds is influenced by two factors. The first is the size of field. When fields are only approximately levelled a large field needs high field bunds to ensure that all parts of the fields impound a reasonable depth of water. Fields of 1–2 ha in area with field bunds higher than 1 m, are found in Yemen and up to 4–5 ha in area with very high field bunds in Pakistan.

The second factor is the number of irrigations that are expected. If only one irrigation is likely the field bunds need to be high enough for sufficient water to infiltrate the soil for the intended crop. When two or more irrigations are probable then less water needs to be impounded and lower bunds are used. The water holding capacity of the soils will also be a factor. Makin (1997) describes the variations of the heights of field bunds in the Wadi Rima traditional system in Yemen and relates these to the probabilities of receiving irrigation. Low bunds were found near the mountain front where two or more irrigations were almost assured. The largest bunds, over 1 m in height, were found at the downstream margins of the system where only one large irrigation was possible in years when large floods reached the downstream sections of the wadi or the flood canals.

Figure 7.2 shows high field bunds in Wadi Tuban in Yemen.

Figure 7.3 shows small bunded plots in a spate systems at Yandefero in Konso, Ethiopia. The Yandefero system is characterised by a large number of relatively mild floods, allowing a distribution of water not very different from a perennial system, with secondary canals and fields with low bunds.

Figure 7.3 Yandefero Ethiopia – unusually low field bunds, related to the large number of mild floods

Rules on second turns

Another important water distribution rule concerns the right to a second water turn. Several crops give significantly higher yields when the fields are irrigated more than once and sufficient moisture is stored in the soil profile. Sorghum, wheat, castor and cotton are examples. Sorghum is in fact often grown as a ratoon crop to catch an off-season flood. For other crops, like pulses, one watering is sufficient.

The rules on second turns are particularly important in systems that receive a series of spates in a normal year. This poses a dilemma: can the second flood be applied to land that has already had irrigation or is priority given to those cultivators whose land is still dry? Both situations occur – in some cases upstream landowners being at liberty to take a second turn, as well as to restart irrigation where it stopped previously and in others downstream lands are irrigated before upstream owners can use the water again. In Sheeb in Eritrea for instance preference is given to the 'driest land' first. In fact in Sheeb as far as practical irrigation in the next flood season starts, where it stopped the previous year. Another such case is the Jama Bund in Kharan, Balochistan (BMIADP 1994). The degree in which it is possible to honour these rules depends on the timing and size of the floods. If floods are very small, they may not reach tail-end areas and it may only be possible to apply them on land that was already watered. A variation on the 'second turn' rules is that the right to a second irrigation is only allowed for special crops, such as the most important subsistence crops. This used to be the practice in the past in Rod Kanwah (Pakistan) for wheat and Wadi Tuban (Yemen) for red sorghum.

Clearly, there is a strong link between the rules on second irrigation and the size of the command area. This is also discussed in Chapter 5. Where the demarcated area is relatively confined, second and third irrigations are possible, however when the area is large and dispersed, single irrigations tend to be the practice.

Rules on large and small floods

Finally, the water distribution may differ according to the size of the floods. One example given is the automatic flow division when floods are large and able to break the bunds in the various flood channels. In other systems there are explicit rules on how to accommodate small and larger floods. Small floods tend to be diverted to the upper sections of the command area, if only because small floods are not likely to travel that far. A rare example of explicit rules dealing with floods of different sizes concerns the Irrigation Plan for Wadi Tuban in Yemen, see Box 7.4.

Box 7.4 Water Allocation Rules for Wadi Tuban (Yemen)

The principle of Rada'ah (upstream land first) is applied in Wadi Tuban and gives precedence to upstream users, who have the right to a single full irrigation of their fields before their downstream neighbours, both between and along the main canal systems. Furthermore, the rule has been established that spate water will not be diverted into fields that have already received either base flow or earlier spates. To ensure the efficient use of spate water the allocation is based on the following Irrigation Plan:

- When the spate flow is small (5–15 m^3/s), priority is given to the canals in the upper reach of the Wadi.
- When the spate flow has a medium size (15–25 m^3/s), priority is given to canals in the middle reach of the Wadi.
- When the spate flow is large (25–40 m^3/s), the flow is directed either to Wadi Kabir or Wadi Saghir in the lower reach of the delta, depending on which one has the right to receive the spate water.
- When the spate flow exceeds 40 m^3/s, the flow is divided equally between Wadi Kabir and Wadi Saghir.

7.3 ENFORCEMENT

The extent in which water distribution rules are enforced varies. There is a strong link with the overall governance and the social structure in an area. In the spate systems in the Eastern Lowland in Eritrea farmers have similar access to land and there is no large contrast between large and small landowners. Local government is active and there is well-established organisation of farmer leaders. As a corollary disputes on water distribution are unusual. This may be contrasted to ubiquitous disputes in Tihama systems in Yemen, where powerful parties stand accused of using their power to their own advantage and tail-end areas are increasingly marginalised.

It is not surprising given the nature of the unpredictable and sometimes uncontrollable flood water supplies and changes in system morphology that conflicts over water are common in spate irrigation systems. Spate systems need a far larger degree of discipline than other resource management systems, yet the returns are sometimes small. Enforcement of water distribution rules is related to three factors:

- Local water user organisation
- Relation between water distribution and maintenance arrangements
- Codification of water distribution rules.

7.3.1 Local water user organisation

The topic of farmer organisation is discussed in more detail in Chapter 8.

For a long time, enforcement of water distribution rules used to be the responsibility of local leaders. Until 1950, the enforcement of existing rules regarding the allocation and distribution of base and spate flows at the level of Wadi Tuban, including the length of diversion structures, was the responsibility of the Sheikh al-Wadi, who was appointed by the local Sultan. If upstream users would take water without the permission of the Sheikh al-Wadi, the latter had the power to impose the following sanctions:

- The concerned farmers were not allowed to grow any crop on their fields but the immediate downstream farmers had the right to grow crops on the irrigated fields of their upstream neighbours.
- If crops were already cultivated, the yields had to be given to the immediate downstream farmers following the harvest.

With investment in agriculture in Yemen and the collectivisation of agriculture in South Yemen, the operation and maintenance of the spate irrigation systems were taken over by government employees and staff in the agricultural co-operatives. When the role of these organisations declined, in particular after the reunification of South and North Yemen in 1990, an institutional vacuum was left. This has resulted in more conflicts between up- and downstream users, as the traditional rules concerning the distribution of base and spate flows are no longer being observed, (Al-Eryani & Haddas 1998).

7.3.2 Water distribution rules and maintenance

There is a strong link between the rules on distributing spate water and the organisation of maintenance. In principle the link works two-ways. In many systems the right to irrigation by spate flows is tantamount to one's contribution to repairs to the headworks or flood channels. If one abstains from public duty one is simply not allowed to open the intake to one's field (particularly if the network of fields is supplied by individual intakes). The link works the other way around, because, as mentioned in the introduction to this chapter, water distribution rules will often serve to create a more-or-less coherent group of land users who are dependent on the spate system and will jointly undertake the maintenance of the structures. In particular, the demarcation of the irrigated perimeter is important as this defines who has an entitlement to the floodwater. Without it is difficult to form a group of partners, making the organisation of the recurrent repair work problematic, including the formulation of rules on cost sharing. A second issue is the critical mass required in undertaking repairs. This is particularly relevant when repair is dependent on human labour and draft animals (as was the case in most systems in the past) and a large force is required to rebuild structures and make repairs. When tail-enders are systematically deprived of flood water supplies, they may no longer want to contribute to the maintenance. The critical mass factor hence works as a check on too large an inequity in water distribution. However, the importance of critical mass may be expected to diminish, when maintenance is mechanized or undertaken by government organisations instead.

7.3.3 Codification

In some spate systems the water rights and water distribution rules are codified. The oldest example is Wadi Zabid in Yemen, where the rules for distributing base and spate flows between the different diversion structures were first recorded 625 years ago by the renowned Islamic scholar Sheikh Bin Ibrahim Al-Gabarty.

Rules on spate rights in the larger systems in the Suleiman range in Pakistan (D.I. Khan and D.G. Khan) have been documented in a register, the Kulyat Rodwar, which was prepared by the Revenue Administration during the British colonial period. The register contains a list of all villages responsible for the labour on each bund. A special functionary was responsible for the enforcement of these rules, exhorting farmers to plug gullies and rebuild their bunds. The spate irrigated areas were an important grain basket at the time and also an important source of tax, hence the interest by the Revenue Administration. In recording the water distribution rules also provided the opportunity to resolve a number of long-standing disputes (Bolton 1908).

In the other main spate irrigated area of Balochistan, the long and extensive Nari system in the Kacchi Plains, detailed rules have been written down concerning the breaking of the different bunds in the spate river (see Box 6.4). These rules were enforced by the 'teshildar ghandahat', an official put in place by the then native ruler of the area, the Khan of Kalat, whose land was located at the tail end of the system. After Kalat State joined Pakistan in 1948 this functionary became an employee of the new administration.

Codifying water distribution rules clarifies and completes local water management arrangements and introduces a neutral factor in any dispute. Testimony of the importance of codifying water distribution rules is the continued use made of water registers, prepared as long ago as 1872, in the spate-irrigated area of D.G. Khan, (see Figure 7.4). Yet recording water rights as such is not sufficient to mitigate conflict or ensure that water rights are observed. The vehement conflicts on Wadi Rima in Yemen – in spite of codified water rights stretching back over the centuries, Makin (1977) illustrates the point.

Figure 7.4 Pakistan: Revenue Official using the 1872 record of rights

In all these examples the authority with which the rules were enforced has declined. It is particularly striking – as one could also expect the opposite – that enforcement has declined as water became scarcer. There are a variety of reasons for this:

- Decline in both traditional and modern government as the rule enforcing mechanisms.
- Decline in spate systems, with increased use of groundwater in the spate command areas.
- Confusion of responsibilities related to system management after public investment in the system.
- Change of opportunities with the introduction of mechanised power.

It is more common for water distribution rules not to be formally registered, even in relatively large systems. In some systems this is because there is little competition for the floods as the distance between the mountains (where the spate flows arise) to the sea or the main river (where they discharge) is short.

Even when there are no formal rules local district officials are often requested to intervene in conflicts in spate systems – particularly where it concerns water rights between different areas.

In smaller systems and within tertiary units enforcement is by local arrangement. Many systems have water masters who usually supervise water distribution and organise maintenance.

7.4 CHANGING WATER DISTRIBUTION RULES

Water rights in spate system are not static. They change under the influence of factors such as population increase and the pressure for new land development, changing cropping patterns and new marketing opportunities; the introduction of more robust diversion structures; shifts in power relations; and changing levels of enforcement. The link between enforcement and overall governance is very strong. There are several examples were new water rights have been created by power play and intimidation, particularly in the spate systems in the Tihama Plains in Yemen. The development of water rights in Wadi Rima (Yemen) during the last few centuries illustrates well the factors operating in the allocation and distribution of base and spate flows (see Box 7.5). The skewed local power distribution, the weak nature of local government and the absence of effective countervailing power create the setting for the 'capture' of spate water rights by strong players – literally bulldozing their way through. In Wadis Zabid, Siham and Mawr there have been examples of major upstream land development and water diversion by powerful parties in contravention of existing traditional rights or legal injunctions. This has been propelled by the possibilities of highly profitable banana cultivation on the basis of conjunctive use of groundwater and spate flows. In contrast far less of this reported from Eritrea or South Yemen, where the social structure has been far more egalitarian and the role of local government stronger.

Box 7.5 Changing Water Rights in Wadi Rima (Yemen)

At the end of the 17th century, four main canals were irrigating fields in the middle reach of Wadi Rima, which were constructed by the first settlers. During the last three centuries, the allocation and distribution of base and spate flows along Wadi Rima were affected by the following developments:

- In 1703, the right of abstraction was extended to downstream farmers by granting them the right to take water for 20 days in November, 10 days in June and 10 days in August. The resulting abstraction restrictions were confined to the upper four canals and not to additional canals further upstream, probably because they only took small amounts of water.
- In 1809, the customary water allocation rights were established for six different shaykhdoms and it continued to function without any major change for about 100 years. These water allocation rights only apply to low flows (i.e. base and flood recession flows) and not to flood flows.
- Due to the development of two upstream canals around 1900, farmers from the middle reach felt it necessary to take action through the courts to establish their prior rights to the low flows. They succeeded in obtaining an injunction to block the two new canals until such time as their four canals had taken all the low flows to which they were formally entitled without any restrictions on the cropping intensity nor the number of irrigations per crop.
- Following a civil war between the Imam and the Zaraniq people in 1928-29, a tract of land was expropriated by the Imam and the Al Hudayd canal was constructed from the point where the wadi emerged on to coastal plain to irrigate that tract of land. Although this new upstream canal initially took a small quantity of water, it took water throughout the entire year, thereby violating the principle that new lands should not be irrigated with low flows. The precedent created was used by landowners on the south bank to abstract the low flow as well. As their canals were much larger, they took the entire low flow at the expense of the downstream users.
- The people, who had lost their traditional access to the dry season flow, protested vehemently and they ultimately took the law in their own hands by breaking the main canal on the south bank. However, the influential canal owner succeeded in jailing the culprits and eventually forced them to repair the canal.
- The irrigation expansion continued on the north bank despite the ruling in 1931 to close the Al Hudayd canal commanding the land of the Imam.
- In 1952, major works were authorised by the Imam to enlarge the Al Hudayd in order to expand the irrigated area. Simultaneously, the Government sold water to people without original water rights at the expense of users with traditional rights to use water of the Wadi Rima.
- Following the revolution in 1962, a committee comprising the Minister of Justice, local magistrates and the secretary of the former Imam ultimately decided that the claims of the people of the south bank should be respected and that the Al Hudayd canal, now supplying government land, should be closed. Until the mid-1970s, however, the Governor of Hudeidah did not implement this decision, possibly fearing the reaction of the people on the north bank (Makin 1977).
- The new modernised irrigation system commissioned in the late 1980s recognised at least some of the claims of the (south bank) middle reach water users. A division structure was designed to provide a 1/3 : 2/3, north bank : south bank division of the flows at the point where the south bank flows were passed under the wadi to the south bank supply canal. However the majority of the water is still being used on the north bank – the powerful north bank water users have vandalised the control gates at the flow division structure and the operating agency does not have the power to impose the water distribution envisaged when the scheme was modernised. The impact this has had on *de facto* water rights is discussed later.

Water distribution rules have also changed – often unwittingly – as a result of external investments in spate irrigation, from the construction of civil head works or making bulldozer time available. The construction of new permanent more robust head works has often resulted in better upstream control, integration of previously independent systems; more controlled flow and changes in the maintenance requirements. The impact of these changes is summarized in Table 7.2 and described next. They all result in greater control by upstream water users.

Table 7.2 Effect of engineered headworks on water distribution

Larger upstream control	Put upstream land users in position to control flows that would have destroyed there intakes in the past Decreases downstream access to flood flows and larger flood recession flows
Combining independent intakes	Creates dependency and creates new tail enders – water being distributed sequentially, where earlier each area diverted part of the floods
Controlled flows	Controlled flows reduce risk of scour and gullying, but the attenuated flows may no longer reach the extreme ends of the command area
Changed maintenance burden	Generally reduces the dependence of upstream land users on the labour of downstream land users

Provision of better control of water at the upstream end of a system often disturbs the delicate balance that exists between upstream and downstream diversions. It is not uncommon for new structures to create a new water management situation, which over time changes the *de facto* water distribution rules.

An illustration of this is the change in water distribution in Wadi Rima in Yemen after the construction of the head works. In the past the tail-end area had been served by independent intakes. The common head works allowed better upstream control of the spate flows, but over time the volumes of water passed on to the tail area were reduced, (Al-Eryani & Al-Amrani 1998). In the past water was diverted by earthen or brushwood diversion structures, that were usually destroyed during high floods, allowing water to go downstream. Now with a permanent structure in principle only the peak flow crosses the weir, but the lower flows remained upstream because of the way the system was operated.

Another example of the inevitable impact of larger upstream control on water distribution is the Rehanzai Bund (Box 7.6). The Rehanzai Bund case shows that it is hard to make enforceable agreements in the absence of an effective authority and in a situation where people have considerable differences in power. Ultimately this technically successful soil bund increased inequity in the system. In other cases the change in water distribution create severe conflict. One of the most spectacular examples is the flood diversion weir, built on the Anambar Plains in Balochistan (Pakistan). The weir was meant to divert spate flows to the upstream land, but also cut off the base flow to the downstream area. Tensions ran high between both communities and were ultimately resolved when by mutual consent part of the weir was blown up, (see Figure 7.6).

Figure 7.6 Diversion weir where part of the crest was blown-up by farmers as it interfered with the base flows, Pakistan

Box 7.6 The Rehanzai Bund Balochistan

The massive earthen Rehanzai Bund – stretching over 2 km – was constructed at the confluence of the Bolan Rover and an offshoot of the Nari River on the Kacchi Plains of Balochistan. The construction of the bund allowed the control of spate flows in the Bagh area, where previously the spate flow had been too fast to capture. After the Rehanzai Bund was completed a number of well-placed landlords constructed a series of permanent diversion bunds immediately downstream of the new bund. This obstructed the water rights of the tail-end Choor-Nasirabad area. The district administration supported the case of the downstream farmers and instructed the upstream landlords to break the bund after their area had been served. The landlords, who had considerable power and influence, refused to do so. As time passed more and more people had to leave the Choor Nasirabad area for lack of farm income. The remaining group was too weak to exert any influence and the upstream landlords prevailed.

Another change sometimes brought about by engineering interventions is the integration of previously independent systems. A variation of this is when a system with a free intake is replaced with a common controlled diversion. Such changes bring people (sometimes entire communities) together in one system. In the past such communities may have had little affinity with one another and there may have been little interaction between them, but they are forced to work together to distribute scarce water. In some cases this has led to intractable social problems, elsewhere it has prevented integrated systems from materialising. Usually systems are integrated to obtain economies of scale that can justify the large huge investment required in civil works.

8. Organisation and management of spate schemes

Most spate irrigation systems have a long history of farmer management – some of the world's largest farmer managed irrigation systems are spate schemes. The reconstruction of diversion structures across spate rivers and the operation and maintenance (O&M) of a network of flood canals requires strong and effective organisations. The viability of spate systems is often determined by the strength of the organisations involved in its construction and maintenance. A historic example is the ancient Ma'rib dam in Yemen (see Box 1.1) that was sustained by a strong state organisation. The eventual failure has been linked to the diminishing capacity of the State to manage the system.

Large, integrated systems can require relatively elaborate organisations, whereas small run-off-the-river diversions are more easily operated. The larger the system the more difficult it becomes to organise common maintenance activities, not in the least because some areas will always have a larger likelihood of receiving the otherwise unpredictable flood supplies. A second important organisational issue is ensuring that the critical mass needed to sustain the system is retained. The collective work in many spate systems requires a considerable effort that is at risk when people move out, for instance after a prolonged drought, or loose interest in spate irrigation, because of the availability of groundwater irrigation, or having only marginal access to flood water. To maintain the critical mass needed to maintain schemes water distribution rules in many spate systems promote a certain measure of equity between upstream and downstream land users, (see also the Chapter 7). Alternatively less advantaged users are compensated through a lower contribution for maintenance.

While farmer management exists at some level in all spate systems, there are essentially three types of management arrangement:

- Predominantly farmer-management
- Combination of management by local government and farmer management
- Combination of specialized agency management and farmer management.

There is a link with the scale of the systems, as shown in the rather simplified overview given in Table 8.1. Full farmer management is common in smaller systems – on tributaries and small streams. Such systems are often relatively simple to operate. There may be no diversion structures and a simple, almost automatic system of water distribution may be in place. Some small schemes obtain limited support from NGOs. On larger systems the role of the local government becomes more important to mediate in disputes and oversee O&M. Agency management has often followed in the wake of public investment on very large systems.

In the subsequent sections of this chapter examples of the different arrangements are discussed and compared. There is often a flux in the arrangements. Roles of local government and external agencies can increase and decline and farmer roles are redefined in the process. In the past decade there has been a movement in development policy towards strengthening farmer management. The experiences and lessons in irrigation management transfer in spate irrigation are discussed in the next section.

Table 8.1 Overview of management arrangements

Mode of management	Farmer-management	Farmer-management with support of local government	Local government in partnership with farmer management Agency-management
Typical Size	Less than 1,000 ha	More than 1,000 ha	More than 5,000 ha
Examples	Upland systems Balochistan Hadramawt Systems Eastern and Western Lowlands System Eritrea Spate systems Ethiopia	Rod Kohi systems DI Khan and DG Khan (Pakistan) Kacchi and Las Bela Systems (Pakistan) South Yemen Systems in the past	Tihama and South Yemen Systems Gash System (Sudan)

8.1 FARMER MANAGEMENT

Farmer management is common in all spate irrigation systems, but the level at which farmers manage varies. It may range from the management of an entire large system to management of secondary flood canals and to on-farm water management only. Maintenance in spate systems can be extensive: the reconstruction of soil bunds or brushwood diversion structures in mobile wadi beds, or the repeated restoration of field bunds and canal banks. The local organisations operating these labour intensive and unpredictable systems are often intricate and impressive. Box 8.1 gives an example of one of such extensive system of resource used in a difficult environment: the remote Korakan river that tends to incise and change course and requires high earth bunds to sustain spate irrigation.

Although farmer management has sustained complex spate systems in several areas, care is needed not to overrate local management. Many rules may be informal and also not entirely clear or comprehensive. Leadership may be 'coincidental' and based on who takes the initiative at the time, or leadership may be contested. Powerful landowners may be able to divert water upstream and create new de facto water entitlements for themselves. Organisation at the lowest level may be weak and it may be difficult to mobilize contributions. Existing arrangements may become unstuck, when faced with a new situation – such as the introduction of heavy machinery or new infrastructure, changes in the river course, or the introduction of groundwater based agriculture.

In describing the arrangements for farmer management there are four main factors:

- Rules on maintenance and water distribution
- Internal organisation
- External support mechanisms
- Activities beyond spate management.

8.1.1 Rules on maintenance and water distribution

Water distribution rules in spate irrigation system are all-important, as they define who has access to the floodwater and on what terms (see also Chapter 7). Water distribution rules are hence crucial to the way maintenance is organised in spate irrigation. Some rules will help create an inner group that will take the lead in maintenance, whereas other rules will expand the number of land users that share in the water and shoulder the burden. Examples of rules that create a privileged core group are 'upstream first' rules and the practice whereby upstream farmers can take advantage of a second water turn before all downstream land is served. Mitigating rules that spread spate water in a relatively egalitarian way include the demarcation of command area and restrictions on the depth of irrigation and second water turns. The scale of the flood irrigation system is an important factor in applying mitigating rules. Mitigating rules are more feasible in small systems than in large systems. As a system becomes larger and more complex, it is increasingly impractical to enforce water supply restrictions on upstream landowners, because of the cost of policing such measures and because small floods will often not reach tail areas anyhow.

Because the area of irrigated land fluctuates widely from year to year, it is difficult to match maintenance contributions to actual irrigation, as is the case in perennial irrigation. In maintenance of spate irrigation systems there is often an inevitable degree of unfairness, summarized in the Yemeni saying that '*he who pays is the laughing-stock of the man who has the right to water first*'.

Box 8.1 Farmer-Managed Spate Irrigation Systems on Korakan River, Balochistan

The different soil bunds along the deeply incised Korakan River in Kharan, Balochistan are fully farmer-managed. The existing O&M practices for a number of larger bunds illustrate the capacity of farming communities to manage their spate irrigation systems without substantial government support.

The *Jama Bund* with a command area of more than 2,000 ha, normally breaches four to five times during the flood season. Farmers are able to rebuild the bund within five days with the help of tractors, whereas it took one month to undertake this work with the help of bullocks in the past. Each farmer has to contribute labour and cash in accordance with the size of his irrigated land. If a farmer does not contribute his share, he loses automatically his right to use spate water for irrigation purposes. In 1992, the farmers spent PKR[8]15,000 for renting tractors. The O&M of the entire spate irrigation system is carried out without the employment of a canal master.

The *Shah Bund*, which was made of sand, breaches partially with every flood and 20 to 25 farmers are able to rebuild the breached portion within one to two days with the help of their own oxen. Each farmer has to contribute labour for the repair of the bund according to size of his irrigated fields, even if he has already irrigated his land. The reconstruction of the bund and the distribution of spate water are undertaken without the supervision of a canal master.

The *Nothani Bund* normally breached once every three to four years. If the bund breached, the community of about 100 farmers were able to reconstruct the bund within a few days with the help of their bullocks. A canal master (*miriaab*) is in charge to organise the reconstruction work and to mobilise the farmers, who are supposed to contribute labour in accordance with the size of their irrigated lands. If a farmer did not contribute his labour share, he was fined PKR50 for each missed working day.

The *Madagan Bund* was breached by every large flood as it was made of sand. Until 1992, about 80 farmers rebuilt the breached bund with their bullocks within a couple of days. If the damage to the bund was very large and the farmers were not able to undertake the reconstruction works before the next expected flood, they could call the help of other farmers from other areas on the basis of mutual assistance (*asher*). In 1993, the bund was rebuilt with bulldozers, whereby 200 bulldozer hours were provided by a local politician and an additional 100 hours were paid by the farmers.

[8] Pakistan Rupees (PKR) US$1 = 60PKR

Box 8.1 Farmer-Managed Spate Irrigation Systems on Korakan River, Balochistan (continued)

The *Karkhi Bund* commands an area of more than 1,200 ha and farmers from 12 different communities have to contribute labour and cash for the maintenance of the bund and the canal system according to their respective land shares. In case the bund has been washed away by a large flood, bulldozers are rented and the necessary cash contributions are collected by the village leaders in each community.

There are several types of arrangements that relate maintenance contribution to water allocation:

- **Contribution according to shares**. A typical example of this is the *jorra* system, practiced in many spate irrigation systems in Pakistan. A *jorra* stands for a pair of bullocks – the unit of work in the repair programs. Agricultural fields are also measured in terms of *jorra*; the amount of land that can be cultivated with one pair of oxen. The shareholder has to participate with his oxen, in accordance to his land share irrespective of whether it was irrigated or not.
- **Graded contributions**. This is particularly common in the larger spate systems of the Kacchi Plains of Balochistan or the now disused spate systems in Saudi Arabia, (Wildenhahn 1985). Different villages had to contribute different maintenance levies – with areas in less privileged places contributing proportionally less to the collective effort.
- **Contribution according to capacity**. This is a variation on the two systems above. In accordance with their land shares farmers are expected to bring bullocks to the common maintenance work. Farmers that do not own draught animals, however, are expected to only bring their own labour. As ownership of draught animals is a fair reflection of the returns from spate irrigation in the previous years, this system is largely fair.
- **Contribution according to benefit**. An example of this arrangement comes from Dameer Bakar in Tareem District (Hadramawt, Yemen). One-fifth of the crop is set aside to pay for the maintenance. This arrangement works well in systems, where the benefits are guaranteed, but would be ineffective in systems, where there is a genuine risk that a number of years go without agriculture.
- **Contribution by contract**. In this arrangement only those who want to be entitled to water contribute. This is system practiced in the Toi War system in Balochistan. Only those who want to receive water contribute to maintenance. All others are expected to close their field inlets. This system is only practical in relatively small system, where it is easy to check on earlier contribution. The system cannot be used in field-to-field systems, where opting out is not an option.

An important requirement of the maintenance arrangements in place is their robustness, i.e. the degree to which they will ensure the constant rebuilding of the common works. This is particularly challenging when the work that needs to be done is substantial and there is a large chance that there will be years without irrigation for a large part of the command area. In these circumstances (graded) contributions on the basis of land shares have a larger resilience than contribution on the basis of benefit, capacity or contract. To avoid loosing the contributions of the tail enders, the likelihood of mitigating rules will be larger in such systems.

8.1.2 Internal organisation

In most farmer-managed spate irrigation systems overhead and transaction cost are kept at a bare minimum. It is common to have a committee of experienced farmers supervising the works on a honorary basis. The committee may meet regularly and invite all farmers, depending on the strength of the local organisation (see Figure 8.1 and also Box 8.2). Other committees come together less frequent and invite office-holders only.

Figure 8.1 Meeting of farmers and local government officials, Wadi Laba, Eritrea

Box 8.2 Committee Meetings in Bada, Eritrea

The first meeting of the committee and group leaders is usually held after the harvest to discuss the reconstruction of the diversion structure (*agim)*. The second meeting takes place after the reconstruction work to evaluate the work on the *agim*. The third meeting is held before the start of the planting season to discuss if diversion structures require additional maintenance and if measures to avoid crop damage by pests and livestock are necessary. During this meeting the committee usually also decides which fields should be irrigated with the water of late floods. The fourth meeting takes place after the planting period to organise crop protection and to discuss measures to control damage by floods especially in the field to field system. Meetings should be attended by at least two-third of all farmers. Farmers absent during a meeting have to accept the decisions made.

(Haile 1999)

Maintenance is usually organised as common labour. It is usual for a series of days to be planned, during which all farmers take their earthmoving equipment and draught animals and provide free labour for the execution of the maintenance works. This simplifies work arrangements and makes it easy for all to see who is present to make his contribution and who is not. In many spate systems increasing use is made of bulldozers and front loaders, available at subsidized rates in some areas. This is discussed in Section 8.1.3. In some of the larger spate irrigation systems in the Kacchi Plains, in Pakistan a water tax, called *gham*, is still collected through a network of local leaders.

The number of paid functionaries is usually small and seasonal. Remuneration is in most cases in kind (dispensation from maintenance labour, share in the crop). This contrasts with government staff, working on spate systems (see Section 8.3), who are usually paid in cash and are retained all the time. Many smaller systems are run with little formal organisation, e.g. some of the small systems in Haudramat in Yemen. The spate water follows a set route through the canal system and excess water is channelled back to the wadi. If water flows in a branch channel a farmer can take the water. If they are not interested they keep their field inlets closed. No one supervises the water distribution.

In larger farmer–managed systems functionaries are appointed. In the Kacchi Plains and *rod kohi* areas of DI Khan and DG Khan, 'engineers' (*raakha*) are appointed for the supervision of the construction of the large earthen bunds and to check the safety of the bunds during the flood season. In some of the larger spate systems in Yemen water masters are employed by farmers to ensure that water is fairly distributed between and along the main flood canals. In a few spate irrigation systems in the Las Bela region in Balochistan, '*sepoys*' are engaged. Their main role is to mobilise, if necessary by force, farmers to contribute to the reconstruction of the diversion structures. This position was established at a time when native rulers organised the construction of the diversion structures with forced labour. After the dissolution of the princely state and the formation of the State of Pakistan, farmers continued with the employment of the '*sepoys*' as they valued their role. The most common function however is that of water master – called *rais, arbab,* in various areas in Pakistan, *sheikh-al-obar* or *sheikh-al-shareej* in Yemen, *ternafi* or *tashkil* in Eritrea. The water master coordinates the water supply to the flood channel and sees to it that water is adequately distributed along the channel or sections thereof, assesses the repair works and mobilizes the contributions for maintenance. An overview of typical farmer-employed functionaries and their scope of work is described in Box 8.3.

Box 8.3 Examples of traditional water management functions

Main system (main diversion)	
Sheikh al-Wadeyeen (master of two wadis) Wadi Tuban, Yemen	***Raakha (engineer/guard on earthen bund), DI Khan, Pakistan***
• determine the water share of each main canal following consultation of each *Sheikh al-Obar* (canal leader) • decide the number of days that water is allocated to each main canal; and • decide the required works to divert spate water into the main canals	• supervise the layout and position of earthen bund, when it is constructed • before the rainy season inspects the structure and points out weaker sections • vigilance during the spate season and communication with individual field owners, water user association, down stream farmers and with revenue department • witness breaching of the *sadd/Ghandi* • keep contacts with *raakha* of next downstream structure(s).

Box 8.3 Examples of traditional water management functions (continued)

<table>
<tr><th colspan="2">Subsystem (flood canal)</th></tr>
<tr><td>Ternafi (subcommand leader), Sheeb, Eritrea</td><td>Sheikh al-Shareej, Wadi Zabid, Yemen
Sheikh al-Obar, Wadi Tuban, Yemen</td></tr>
<tr><td>• assess the amount of labour required to carry out specific works
• mobilise labour for maintenance of irrigation structures
• supervise the works undertaken by farmers of his group
• check if all fields in his group receive irrigation water
• convey information and directives from the local administration/Ministry of Agriculture to the sub-group leaders
• investigate reasons when a farmer has not contributed labour during collective works
• transfer messages and requests from to the local administration
• prepare written reports about the works undertaken by his group</td><td>• assess the quantity of water going into the primary flood canal so as to avoid erosion
• enforce water distribution rules and supervise water distribution;
• decide which particular plot of land has the first right to receive water when the next flood comes
• calculate the O&M costs and to charge each farmer proportional to his irrigated area
• mobilise farmers for the reconstruction of the diversion and control structures and the cleaning of the canals
• settle any dispute among water users and report violations</td></tr>
<tr><td colspan="2">Block (part of flood canal or branch channel)</td></tr>
<tr><td>Tashkil (block leader), Sheeb, Eritrea</td><td></td></tr>
<tr><td>• monitor the progress of field bunding
• to organise and supervise larger teams of farmers to work on the main structures
• implement community rules for the management of flood water
• secure water delivery to the branch canal where is sub-group is located
• impose fines on those who waste or steal water from adjacent fields
• collect land tax among the individual farmers in his sub-group</td><td></td></tr>
</table>

Not all functions are paid or compensated in kind. In the Wadi Laba system in Sheeb, Eritrea there is well-articulated system in place of unpaid water masters both at the level of main groups, served by primary flood canals and the level sub-groups or blocks. All in all, there are 18 main group leaders and 77 sub group leaders (Haile 2003), some of the latter, women (see Figure 8.1). The area served is 2,800 ha and hence the management density is very high. The water masters are not paid and they also take on board other tasks, particularly in distributing agricultural inputs. The main group leaders coordinate in an Irrigation Committee, that decides on the water distribution between the main command areas. In other systems in the area similar articulated arrangement is in place, (Haile 1999).

The existence of sub-groups makes it easy to mobilize labour for maintenance at block and group/ flood channel level. It also facilitates the implementation of rules on the maintenance of field bunds etc. The sub-group leader (called *tashkil* in Sheeb) is an important go-between for individual farmers in his sub-group and the water master/leader of the farmers' group. He/she conveys instructions of the group leader to the individual farmers and submits messages and requests of individual farmers to the group leader. The sub-groups may be formed on the basis of branch canal or because houses are in the vicinity of each other or their fields are situated next to each other. Traditionally, the sub-group leaders were elected directly by the individual farmers of each farmers' sub-group, although the Ministry of Agriculture is sometimes involved. In order to be elected as sub-group leader, a candidate should be physically fit, having authority to mobilise the farmers for collective labour and preferably be literate. It is also crucial that a sub-group leader does not move from the area. The sub-group leaders are not remunerated for their efforts.

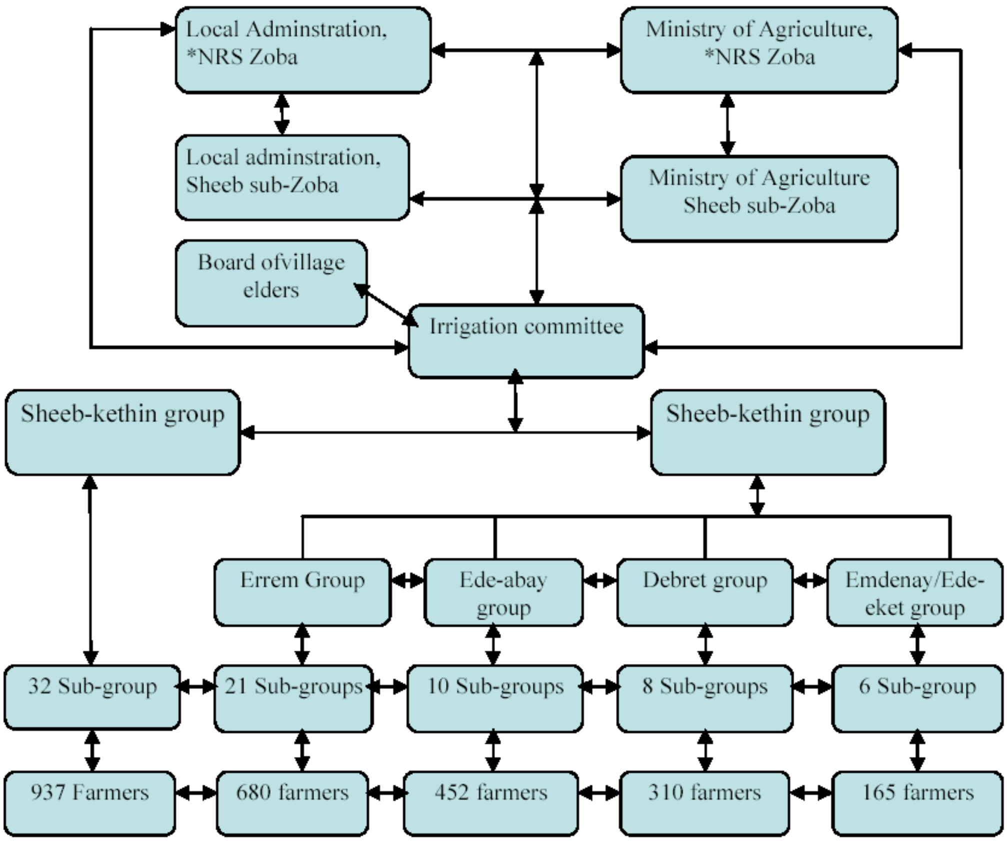


Figure 8.2 Wadi Laba, Eritrea, Farmers' organisational structure and its links to government institutions (Haile 2003)

8.1.3 External support: bulldozer programmes

In addition to the resources mobilized internally, farmer organisations also often use external support. Particularly since the 1970s bulldozers have become popular in Pakistan for rebuilding soil bunds, plugging gullies in the command area and making field bunds. In many spate areas the availability of bulldozers has revitalized farmer-managed spate irrigation.

Balochistan Province in Pakistan has probably had the largest infusion of mechanical equipment. In 1948 the Department of Mechanised Cultivation was created equipped with seven old bulldozers, purchased from the military. These bulldozers were used to develop agricultural lands and conserve the moisture in bunds by raising earthen embankments. From the sixties onwards the fleet of machines expanded rapidly, much of it by tied aid programmes from Russia, Italy and Japan. By 1975 the Department possessed 231 bulldozers. This number further increased to 321 in 2002. There has been a large fall-out though, because of heavy use and insufficient maintenance. Of the total number of bulldozers and front loaders approximately 70 percent are operational.

Bulldozers have been made available at substantial subsidy in Balochistan. Rental prices to farmers have been as low as US$1 to 5/hour, covering less than 10 percent of the operational cost. The usual practice has been for farmers to take care of the bulldozer operator and encourage him to work effectively by providing a gratuity, food and cigarettes, paying for assistants and at times also paying for fuel and small repair costs. From 1985 political office holders (members of the provincial and national parliament and senate) were privileged to distribute such 'bulldozer hours'. Testimony of the importance of bulldozers in land and water management, this programme turned into one of the most popular programmes of political patronage in the Province. Common practice is to give the bulldozer hour allocation to a village leader that was instrumental in collecting votes. During 1990s bulldozers time allotment was more than the working capacity of the bulldozer fleet in the province. The position of Minister of Agriculture was very much coveted, precisely because it gave access to this resource. Bulldozer are used for a variety of purposes, but in spate irrigation areas they have been particularly popular because they allow the timely reconstruction of the massive earthen diversion bunds.

Figure 8.3 Earthen diversion bund (ghanda) constructed by bulldozer, Pakistan

It can be argued that if it had not been for the availability of bulldozers spate irrigation would have been in decline in Balochistan. The social organisation required to mobilize human and animal power for construction of diversion structures and flood channels has been difficult to sustain in places. The same applies to other areas. In the Sheeb systems in Eritrea bulldozers were employed to plug gullies, that were created through out the irrigated areas after uncontrolled flooding, vastly improving local soil moisture retention.

Figure 8.4 Bund constructed by bulldozer plugging a gully in the irrigated area formed by earlier uncontrolled flooding

The intensive use of bulldozers can have drawbacks. Research in DG Khan in Pakistan points to the inexperience of some of the bulldozer operators, resulting in inappropriate structures. Training of bulldozer operators and making them work under the aegis of local farmer leaders were recommended. In other places there is an overall shortage of skilled bulldozer operators. Another drawback was discussed in the previous chapter. The use of bulldozers to construct higher and stronger soil bunds has jeopardized downstream water allocations in several places.

8.1.4 Other functions

The main task of local farmer organisations in spate systems has been the organisation of maintenance and the enforcement of water distribution rules. Some organisations have also been active in agriculture, in particular in pest management.

It is useful to consider these local organisations as 'social capital', that may also be engaged in other purposes. One such area is groundwater management. Experience of several areas has shown that the only successful examples of groundwater management were based on self-regulation (van Steenbergen & Shah 2002). In several spate systems – particularly in Yemen – irrigation is increasingly 'conjunctive', using both spate flows and groundwater. This has resulted in severe declines in water tables and in coastal Yemen, ingression of saline water. It also jeopardizes the use of groundwater for domestic and drinking water purposes.

8.2 FARMER MANAGEMENT AND LOCAL GOVERNMENT

Where systems become larger, the role of local government in management – be it local administration or traditional local leadership – becomes more important and complements that of local farmer organisations. There are several examples where local government has played a constructive and supplementary role in organising maintenance and supervising water distribution. Particularly because of the 'reactive' nature of water rights in spate systems, strong legitimised authority is crucial in the management of large spate systems. In the Sheeb system described earlier, different rules and regulations were formulated and applied by farmers to fine individual farmers who did not contribute labour as required, or who were breaching a main canal, field bunds or a field gate without permission. Livestock owners could also be fined if their animals cause damage to standing crops in the fields. As many groups in the Eastern Lowlands had problems with the enforcement of these rules and regulations, they had to request the local administration to use its power to collect the fines. In 1995, the three Irrigation Committees were requested to draft uniform rules and regulations in negotiation with the local administration. Subsequently the newly drafted rules and regulations have been issued by the local administration as its official rules for its entire area of jurisdiction. In Bada, in another part of Eritrea the local development council (*baito*), formed during the country's liberation struggle, took over the overall management for the construction and repair of the irrigation structures (Haile 1999).

Unfortunately in several other parts of the world the positive contributions of local government have been eroded with the general decline in governance and loss of trust.

Another prime example of a constructive role of local government in spate irrigation comes from DI Khan and DG Khan in Pakistan. From 1872 the colonial Revenue Administration recorded the rights and rules in the spate irrigation systems, after endorsement by local leaders. To date these documents remain an important reference for any arbitration and conflict resolution. Apart from the settlement of rights, Revenue Staff also oversaw on a day-to-day basis the distribution of spate water, urging repairs and the plugging of breaches. Traditionally, local user associations took care of the maintenance, providing labour, traction animals and material. The role of the colonial administration was to 'organise' these activities during peak periods and emergencies. Farmers that did not take part in the 'kamara' (collective maintenance activities) were fined. In addition labour was also at times brought in from neighbouring areas. This engagement had a number of positive political side-effects. Grain production increased in a remote border region of British Indian empire – bringing stability and creating goodwill among the non-controlled tribal population. New areas were brought under cultivation, resulting in settlement and an increase in land revenues.

Within the revenue department of the local administration, Rod Kohi departments were established that continued to exist after independence. They come under the Deputy District Officer, who until recently had the powers of magistrate and could fine, penalize and have defaulters or violators arrested. The Rod Kohi department is made up of mainly regulatory staff, engaged in conflict resolution and safeguarding the application of flood water rights. The local engineering was left to farmers.

Table 8.2 Staff composition of Rod Kohi departments, Pakistan

	NWFP		Punjab		
Staff Position	**DI Khan and Kulachi Teshils**	**Tank District**	**DG Khan Districts**	**Rajanpur District**	**Remarks**
Spate Command Area	*224, 000 ha*	*118,000 ha*			
Deputy District Officer Revenue/Rod Kohi	1	1	1	1	General administration of District; general supervision; power of magistrate; final authority in conflict resolution
Tehsildar	1	1	1	1	Daily supervision; power of magistrate; contact with farmers
Naib Tehsildar	2	1	2	2	Assistant teshildar
Qanoongo/ Darowgha	2	5	7	2	Supervision, daily contact with farmers
Patwari/ Naib Qasid	8	6	10	2	Maintains records of rights
Muhafiz (reader)	1	3	2	2	Watchman/reader of flood measurement
Temporary muhafiz		8			
Auxiliary staff	8		33		
Facilities	Office facilities Jeep Telephone for DDO	Office facilities No jeep No wireless	Office facilities No jeep No wireless	Office facilities No jeep No wireless	

Given the magnitude of the area under spate irrigation, the staffing levels are very modest. The explanation is that a strategy of enabling governance is in force. Contrary to perennial canal systems, the policy has been to follow local decisions in case of disputes occurring in spate related issues. Local elders and community members are expected to reach consensus on sensitive issues. The administration facilitates the process and intervenes only when necessary. One of the most important points has been not to prolong spate irrigation related cases in courts of law, but instead give the final authority on arbitration and adjudication to the deputy commissioner at district level.

These arrangements changed with the decentralization of 2001. Before 2001 the District Government had the authority to check on illegal action of farmers under the Minor Canals Act. The *Naib Tehsildar* could punish and fine accordingly in cases of violation of the indigenous rules agreed upon by all members of water user association/share holder/farmers. It was very common for *naib teshildars* to issues non bailable warrants to farmers failing to contribute to the collective labour. After the devolution of administration in Pakistan, these powers and authorities have been withdrawn from the revenue department and direct involvement of officials is in theory not possible. Now that the department faces unrest and resistance some rearrangement is in progress. Government is working to make the new local government system more compatible with local situations. Under the new system the political elected person called district *nazim* is head of administration.

A third example of joint management by farmer groups and local government – with local government in a steering and facilitating role - comes from South Yemen. Until 1950, the *Sheikh al-Wadi* (Master of the Wadi) was responsible for the management of the entire Wadi Tuban on behalf of the Sultan of Lahej. The main responsibilities of the

Sheikh al-Wadi were to monitor the allocation and distribution of spate water in accordance with existing rules and regulations; to decide on the length of each *uqma* (i.e. traditional diversion spur); to decide on the allocation of small and medium spate flows that cannot reach the tail of the spate river; and to impose and enforce sanctions for taking water without prior permission.

From 1950 to 1967, the role of the *Sheikh al-Wadi* was taken over by the Agricultural Council that was established following the issue of a decree by the Sultan. The Agricultural Council reported to the Sultan and the Director of the Agriculture Department as chairman and 17 to 24 representatives of landowners and sharecroppers, who were selected on the basis of their experience and knowledge. In 1954, the Agricultural Development Board was established to introduce the cultivation of cotton in the spate irrigation systems of Wadi Tuban. The Board became in charge of the irrigation works and O&M services, where the costs were covered through the collection of irrigation fees based on irrigated area.

The basis for the management of the system was an elaborate set of rules, the governance arrangements (composition, function and meeting) of the council, rules for water distribution rules, including compensatory water allocations, cost contributions, the funds managed by the council, arbitration procedures through the Agricultural Court, agricultural transactions, standard lease and tenancy arrangements, penalties for unauthorized use of flood water or base flow, penalties for negligence of canal banks (causing water to escape to another area), penalties for failing to contribute to maintenance and penalties for failing to pay fines. The governance arrangements from these rules, explaining the scope of activities of the Agricultural Council is given in Box 8.4.

Box 8.4 Governance arrangements in the Agricultural Council Tuban

Composition

- Director of Agriculture (chairman), Permanent Secretary of the Department of Agriculture (deputy chairman) and seventeen to twenty five members, representing the landlords and cultivators.
- *Mashayikh al-A'bar* (supervisors of channels) from the two wadis may be invited to attend meetings but their opinions shall be advisory in nature.
- The Director of Agriculture shall submit to H.H. the Sultan a list of the names of those whom he nominates for the membership of the Agricultural Council and H.H. the Sultan shall select from among them the required number.
- The term of membership of the Council shall be for two years as from the date of appointment.

Functions

- Rationalization of the irrigation problems.
- Protection of the *aqna* (the right proportions of water established by custom for the irrigation of individual parcels of land) and the *raddyi'* (the sequence of allotting irrigation water to channels and parcels of land established by custom) and the allotting to each channel, barrage, sub-channel and 'marginal' channel, the amount of water to which it is entitled according to the established system (i.e. the custom).
- Rationalizing [the rules of] *ijdrah* (tenancy) and *sharak/shirk* (share-cropping).
- Distribution of land among small and large cultivators.
- Division [of water] between the *wadis.*

Box 8.4 Governance arrangements in the Agricultural Council Tuban (continued)

- Maintenance of channels and barrages.
- Devising of a system for dealing with the irrigation of lands which are forced to pay *furuq* (contributions for the maintenance of channels) and *masarih,* (contributions for the building of barrages in the *wadi)* each year notwithstanding that they remained unwatered.
- Regulation of maintenance charges on channels and *wadis and* assigning a special fund for them.
- Introduction of a special system for the irrigation of land is planted with red sorghum and provision for their second watering so that the local food security is ensured.
- Scrutinise agricultural land sales and purchases.
- Review penalties applied to offenders and transgressors.
- Issue annual report of revenues and expenditure, submit it to H.H. the Sultan and then have it published for the information of the public.
- Issue bye-laws and put them into execution after obtaining the assent of H.H. the Sultan.

Conduct of Transactions

- The Council shall be convened twice each month and during the spate season at least twice weekly or at any time wished by the H.H. the Sultan.
- If a member fails to attend four consecutive sessions without permission or adequate excuse, such a member shall be regarded as having resigned.
- The Chairman shall preside over the meetings and the Permanent Secretary shall deputize for him in his absence. If both are absent a Chairman shall be elected for the Council from among those present.
- All decisions of the Council shall be taken by simple majority vote but when the votes are equal the Chairman shall have a casting vote; and a quorum shall be considered to be established only when more than half the number of Council members are assembled.

Source: Maktari (1971)

This system came to an end with the creation of an independent South Yemen in 1967 and the introduction of the socialist regime. The Agricultural Council was replaced by an Irrigation Council. Members of the Irrigation Council were Directors of State Farms, farmer representatives from State Farms and Cooperatives as well as political leaders and representatives from the Agricultural Cooperative Union. The Agricultural Development Board was replaced by the Public Corporation for Agricultural Development for Tuban Delta, which became responsible for the O&M services but without the authority to recover any costs from the farmers or their cooperatives. This governmental ‘agency-managed’ approach was carried forward. From the early 1980s, the responsibility for the O&M of the spate irrigation systems was transferred to the irrigation section of the Ministry of Agriculture. After the unification of South and North Yemen in 1990, the Regional Irrigation Department of the MAI also made no attempt to recover the O&M expenditures on the modernised spate irrigation systems. In 1996, the Governor of Lahej and the MAI issued Resolution 14/1996 and Decree 7/1996, which re-established the Irrigation Council. The Council however is not empowered but merely consultative in nature and advisory in outlook. The Irrigation Council comprises the District Commissioner as Chairman, the Director of Agriculture as Deputy Chairman, the Director of Irrigation as Secretary and again has 14 farmer representatives as members, who are permanently appointed. In its consultative and advisory role, the Irrigation Council formally has to discuss and approve the irrigation plan as proposed by the Director of the Regional Agricultural Office; decide on how floods can best be used; and assist in the management and maintenance of the irrigation structures. Management of the spate system irrigation in Wadi Tuban has however become confused, as it is no longer clear who is in charge. As a result the Local Council, the Irrigation Council as well the Irrigation Department of the MAI all order instructions on the distribution of water.

8.3 AGENCY MANAGEMENT

Where specialized agencies have taken responsibility for the management of spate systems, it has usually been the outcome of public investment in spate irrigation. Not all government investments have had this outcome. The role of the Irrigation and Power Department in the management of the government-constructed spate irrigation systems in Balochistan has been limited to the appointment of O&M staff and guards and the execution of repair works on an ad hoc basis. The Irrigation and Power Departments did not have a routine maintenance programme and the already inadequate budgets for maintenance were further curtailed during the 1990s. Also in other areas – DG Khan, DI Khan (Pakistan), Hadramawt (Yemen) or Eritrea for instance - public investments in spate systems have not resulted in agency-management, though in some cases government has assumed responsibility for larger repairs.

The two main examples of agency management to date are the modernized systems in the Tihama, managed by the Tihama Development Authority and the Gash System in Sudan. Agency management has suffered from:

- An inability to live up to the promise of basic maintenance as a result of under funding.
- An inability to manage and distribute water in a moderately fair manner because of poor links to farmer organisations or local government.
- Continued high expectations.

The prime example of agency management is the Tihama Development Authority in Yemen. From the 1970s onwards the TDA became responsible for the operation and maintenance of the large spate irrigation systems, modernized under the large World Bank funded Tihama programs. TDA’s responsibility formally extended down to the level of field turnouts. In the new scheme of things farmers’ responsibility formally reduced from managing large complex traditional systems to diverting water through field ditches to their fields. Farmers in the Tihama were required to pay 2 percent of their agricultural production from spate irrigated fields as an irrigation fee, but this system was never implemented. As a result, the TDA often lacked the necessary funds to undertake the O&M necessary in modernised spate irrigation systems.

Table 8.2 illustrates this trend. The O&M budget received for Wadi Zabid and Wadi Rima, both managed by TDA, are significantly less than what was requested or what is desired. The same applies for Wadi Tuban and Wadi Bana in south Yemen. These systems had the additional problem an inflated pay-roll, a legacy of the socialist era of the People Democratic Republic of Yemen.

Table 8.3 Actual and optimal O&M in four agency-managed systems, Yemen (1998)

	Wadi Zabid	Wadi Rima	Wadi Tuban	Wadi Bana[9]
Area covered (ha)	17,000	8,000	6,606 (ca 8,000)	12,400 (ca 19,000)
Actual situation				
Staff employed	97		486	395
Staff costs (Million YER)	5.09	3.39	64.0	29.5
O&M budget requested (operational) (Million YER)	10.3	3.2	44.4	30.1
O&M budget received (Million YER)	2.0	1.9	1.8	3.6
Optimal situation				
Staff no	95	59	84	116
Salary costs (Million YER)	9.1	6.1	7.5	11.0
Operational budgets (Million YER)	7.4	4.4	4.5	10.3
Maintenance budgets (Million YER)	1.8	1.5	1.5	2.3
Depreciation (machinery/ vehicles) (Million YER)	32.7	19.9	19.6	47.5
Total including 15 percent misc. (Million YER)	58.7	36.7	38.0	81.9
O&M cost/ha (YER)	3,859	4,583	4,764	4,313
Average cost/ha (YER)	4,432 equivalent to US$32.8			

All costs above in Yemeni Rial (YER) US$1 = 184 YER
Source: Al-Eryani, M. Mohamed Al-Hebshi & Anwar Girgirah (1998)

Earlier the O&M of the spate irrigation systems in the Tihama were organised by traditional water masters. In the past, the Sultans charged certain families with the responsibility of canal masters a position that was inherited. The strong control in the past also restrained farmers from violating traditional rules regarding the distribution of spate water despite the tradition of resolving disputes through conflict. When TDA first asserted its authority it was able to resolve a large number of disputes.

At present, the enforcement of these traditional rules however has weakened as the TDA staff is not adequately supported by the concerned authorities to prevent large landowners operating gates without the permission of the TDA and they are not in a

[9] Upstream section 'modU/s by MAI (4,510 ha), d/s traditional system

position to impose any sanctions. TDA tried to engage the local council to induct farmers but with little success.

From the mid 1980s, the number of water conflicts between up- and downstream farmers increased significantly. This was propelled by the rapid expansion of banana cultivation, causing many upstream farmers divert as much water as possible to their banana fields. In several of the main wadis in the area (Zabid, Mawr and Siham) powerful farmers have literally bulldozed new upstream off-takes through. Due to its growing inability to ensure the equitable water distribution in accordance with the existing rules, the TDA gradually abandoned its supervisory role in this field. At the same time, an increasing number of canal masters have become ineffective or their powers have been eroded due to influence exerted on them by large landowners in the upstream areas.

Box 8.5 Irrigation committees without power – the example of Zabid, Yemen

In 1988, the Ministry of Agriculture and Irrigation issued Decree No.361/1988 with the provisions of establishing Irrigation Committees comprising seven members, of which only two are selected farmers' representatives. The main tasks of the Irrigation Committee were defined as:

- to document traditional water rights and customs as well as land having irrigation rights from base and spate flows.
- to resolve conflicts regarding water allocation and distribution.
- to define the relationship with farmers and outline their duties and responsibilities with regard to the distribution of water.
- to make proposals concerning the role of farmers in the O&M of the spate irrigation systems.
- to provide advise regarding the optimal use of water and assist in the implementation of irrigation plans.

In 1990, the Tihama Development Authority (TDA) issued Decree No.6/1990 to facilitate the formation of the Irrigation Committee for Wadi Zabid with five Government members and two farmers' representatives. According to the issued Decree, the Irrigation Committee only had the right to formulate recommendations, which needed the approval of the TDA Chairman and the Governor. The newly formed Irrigation Committee never became effective. Farmers were insufficiently represented, the mandate was too small to generate interest and neither decrees were fully implemented.

In response to the limited role of the agencies and the limited number of active canal masters, farmers have increasingly taken the initiative to organise the O&M of their irrigation systems themselves without waiting for assistance from outside. To organise and coordinate the O&M, farmers have formed informal groups at village level.

Figure 8.5 Farmers meeting, Wadi Zabid, Yemen

Due to the spontaneous, autonomous organisation of farmers, who are taking action to ensure that the canal system and diversion weirs are operational, the utilisation of base and spate flows are still effective. Most of the maintenance works are executed with the help of their own oxen, while machinery is hired when needed. According to a baseline survey conducted in 2001, farmers receiving water from modernised systems paid an average amount of YER4,000–7,000 (about US$22–38) per year for the O&M, whereas farmers on traditional spate irrigation systems paid about YER20,000 (US$ 108) per year as they have to reconstruct their traditional diversion structures every year, (World Bank 1999, 2000a, 2000b; three PIM Seminar Papers 1998).

A similar experience was seen in the Gash System in Sudan, where the Farmers' Union is supposed to be elected by the farmers in the Project area and intended to represent their interest. Given that the constituency is not clearly defined in the scheme and many farmers do not have ready access to irrigated areas, they lost interest in its administration. The Farmers' Union thus tended to represent the interests of the local tribal hierarchy, tribal sheikhs and elites in the Project area.

Figure 8.6 Farmers using brushwood to head up the flow in a canal in a modernized system, Wadi Tuban, Yemen

Under resourcing was an important obstacle for the now abolished Gash Development Authority (1992–2002). Lacking financial and technical resources the scheme's irrigation infrastructure deteriorated seriously and the Gash system experienced a decline in income – from a cotton export zone it became a marginal subsistence crop area. In 2002 the Gash Agricultural Scheme (GAS) was incorporated by decree to undertake the management of the Gash irrigation scheme. It has a board of directors chaired by the Federal Minister of Agriculture and co-chaired by the State Governor to whom the chairman delegated his powers. GAS activities are focused on the repair and maintenance of canal off-takes. However it is still constrained in its ability to plan for development because of inadequate funding, lack of revenues and technical capacity.

9. Economics of spate irrigation development

Returns to agriculture in spate irrigation generally do not justify large capital outlays, but this has not prevented high investments being made in spate improvement projects. This chapter briefly discusses the economics of spate irrigation, focusing on the costs of improvement options and the assessment of benefits. As discussed in Chapter 11, spate irrigation can contribute to wider basin resource management and these contributions should be included when the usefulness of support to spate irrigation development is being evaluated.

9.1 ECONOMIC ANALYSIS OF SPATE SCHEMES

Any investment in spate irrigation can only be economically feasible if the net economic benefits are significantly higher that the present economic returns from spate-irrigated agriculture. However, the scope for deriving significant additional economic benefits from investments in spate irrigation is limited for the following reasons:

- Cropped area and crop production varies considerably over the years due to the great variation in the size and frequency of floods from year to year and season to season.
- There is the inherent risk of a total crop failure in years with no floods or very floods that wash away the diversion structures before any land could be irrigated.
- Cropping pattern is dominated by the cultivation of traditional crops with low market value, which are mainly grown for home consumption.
- Diversion and conveyance efficiency of many spate irrigation systems is already relatively high as most surface water is used for irrigation.

As the scope of potential economic benefits from investments in spate irrigation is limited and to ensure that the improvement of spate irrigation systems make sense in economic terms, development costs must be curtailed. Appropriate low cost development approaches are described in the next chapter. Apart from costs, a low-cost approach may also have the following significant advantages:

- Simple technology that is easily adopted by local craftsmen are used, ensuring that both construction and maintenance can be undertaken at the local level, using locally available, inexpensive materials.
- Independence from heavy machinery and imported supplies.
- In most situations, the farmers themselves can carry out construction work.
- Repairs are less costly and can be executed faster as only locally available materials and craftsmanship are required.
- The impact of failures is partial as low-cost diversion structures have smaller command areas than larger, permanent diversion structures.

While low cost options are attractive from economic and sustainability considerations, as discussed later it is also necessary to consider the levels of service that are provided. There are few examples of farmers wishing to dispense with even poorly designed permanent diversion structures and return to their previous labour intensive diversion arrangements, although they may often wished to modify them.

The feasibility of investment in spate irrigation also depends upon the probability of receiving water. Areas with a more reliable supply of spate water justify higher levels of investment than areas with less reliable supplies of spate water.

9.2 THE COSTS OF SPATE IRRIGATION DEVELOPMENT

9.2.1 Cost of different engineering options

As discussed elsewhere in this report, there have been several types of programme supporting the improvement or modernisation of spate irrigation, that have had varying degrees of success. Investment in civil engineering to provide permanent gated head works and new canals in large systems has attracted most visibility, but as discussed earlier and in the next chapter, 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 ha for different spate projects. The cost per ha is dependent on the nature and size of the system. In general high costs per ha are incurred in systems that involved the construction of permanent head works and new canals on large systems. Contrary to what one may expect economies of scale do not seem to apply. Unit costs seem to increase in the larger systems. The reason is mainly the technical complexity of larger systems and the much larger wadi flows that have to be allowed for when a conventional civil engineering approach and design safety factors are applied to design of conventionally engineered irrigation infrastructure.

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 head works 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. Also 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 not used due to the difficulty of managing water distribution between both banks.)

There is also an element of ‘management of expectations’ in new engineered schemes. In traditional systems a degree of unpredictability and unfairness and a very high maintenance burden is expected. In externally funded “engineered” projects the standards of fairness and efficiency of water diversion and the requirement to minimise maintenance costs are often put considerably higher.

The cost per ha for system with civil head works on large (1,500 ha and above) systems are between US$1,350–2,000 per ha (with some exceptional peaks above this amount), while the cost for permanent headwork on small systems is considerably less at US$180–450 per ha. The cost for systems with non-permanent head works, essentially soil bunds, is far less again – mainly below US$125 per 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 15 years.

In general permanent head works on small systems, investments in soil bunds or subsidized bulldozer programmes (see Chapter 8) provide high returns and defeat the notion that investment in spate irrigation is not rewarding. As discussed in Chapter 11 such programmes may also 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 (see Chapter 5) through traction programmes, command area programmes (such as gully plugging) and investing in conjunctive use of groundwater and spate flows.

Table 9.1 Development costs of different types of spate irrigation projects, (van Steenburgen 2004)

Intervention	Cost / ha (US$)	Description
Non permanent headworks		
Rehanzai Bund, Pakistan	5	Large soil bund and embankments with gabion core, diversion channels (1984) – irrigating 12,000 ha
Gathelay, Eritrea	51	Soil bunds, gabion structures (2002)
Karkhi Bund, Kharan, Pakistan	70	Bulldozer built soil bund (1993), irrigating 20 ha, but larger potential
Grasha, Eritrea	123	Soil bund and diversion channel
Permanent headwork, small systems		
Alebu, Eritrea	181	Diversion weir and guide bund
Mogole, Eritrea	341	Diversion weir and guide bund
Bultubyay, Eritrea	444	Diversion weir, guide bund, flood channel
Rehabilitation		
Dameers Hadramawt, Yemen	90	Small systems
Dameers Hadramawt, Yemen	151	Small systems
Command area works IIP	150–300	
Sidi Bouzi, Tunisia	252	Small system
Permanent headwork, large systems		
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)
Barquqa, Yemen (revision)	14,000	Diversion weir, new flood channel, siphon Revised and adjusted for actual area (2004)

The costs tabulated above have of course to be related to the level of service provided by the different engineering approaches. Simple soil bund or spur type diversions are cheap to construct with a bulldozer, but have a limited life, often only one or two years and in extreme cases may need to be replaced more than once every year. These systems also require a lot of effort from farmers to operate and maintain, as uncontrolled flows are admitted to canals requiring a large effort in re-constructing canal diversions, repairing scour damage and in some cases in removing sediment deposits. In the right circumstances a simple permanent intake, designed using a "value engineering approach" (Annex 4) and provided with effective sediment control facilities may provide a much higher level of service and dramatically reduced operating and maintenance requirements over an engineering life of twenty or thirty years. Recommendations on the appropriate engineering interventions in schemes with different characteristics are made in later in Chapter 12.

The trade off between initial investment costs and subsequent operation and maintenance (O&M) costs in spate systems deservers more attention that it has been given to date. Data on the O&M budgets for four agency managed schemes with permanent head works and "engineered" canal systems in Yemen were presented in Chapter 8. These indicate an average "optimal" O&M cost of around US$33 per ha in 1998. This is far more than the actual budgets received, which were mostly spent on maintaining a large permanent agency staff, offices, vehicles and other support services. Very little was spent on actual scheme maintenance. At the other extreme the costs of operating and maintaining traditional systems are mostly farmers direct labour and their investment in draught animals. These vary enormously from scheme to scheme and from year to year and are not known with any precision. Haile (1999) reports that in Eritrea in most of the traditional spate irrigation schemes, about 80 percent of the farmers' effort is spent on repair and reconstruction work of diversion structures, field embankments and canals. Some estimates of initial and subsequent maintenance costs, for a range of traditional spate diversion spurs in Eritrea, are presented in Haile (1999).

Table 9.2 Comparison of the costs of traditional types of diversion spur in Eritrea, (Haile 1999)

Type of diversion spur	Initial cost in US$	Estimated damage as percent of initial cost during normal spate season	Number of repetitions of construction during normal spate season	Maintenance cost in 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

Excluding the gabion option maintenance costs for traditional diversion spurs average around 1.6 times their initial cost. This figure can be compared with the same ratio, i.e. annual maintenance costs divided by initial costs for a range of engineering interventions:

Type of engineering	Ration, annual cost of maintenance to initial cost
Traditional diversion spur (Average from Table 9.2)	1.6
Soil bund (bulldozer)[1]	0.33
Gabion diversion(Table 9.2)	0.2
Permanent head works and new canals in large agency managed schemes[2]	0.025

Note 1 Assuming that bund needs to be re-constructed every three years
Note 2 For an initial development cost of US$14,00 per ha and "optimum" maintenance cost of US$35 per ha

While these very approximate figures tell us 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.

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.

9.3 ASSESSING THE BENEFITS OF SPATE IRRIGATION DEVELOPMENT

9.3.1 Time horizons

In assessing the benefits of spate irrigation it may be useful to use different planning horizons, rather than the 20-30 year period that is common in water infrastructure projects. 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. Water users, however, may have a different planning horizon and be willing to accommodate more risks in line with the uncertain and variable nature of spate irrigation. The example of the Sonwah Dam in Balochistan illustrates this difference. In Sonwa Dam farmers accepted the fact that they would have to ‘chase’ the river and did not expect the diversion works to function for a long time. The Sonwah Dam was built at the tail section of the Nara River in Balochistan. In the past spate flows had been diverted in this area but the river had become too wide and too deep and as a consequence uncontrollable. Following the local engineering success of the Rehanzai Bund a similar undertaking was started in Sonwah: the construction of a very long soil bund and embankments spanning more than 2 km. The soil bund would close the entire river section. Farmers expected this to cause the Nara River to silt up. Their estimate was that it would take seven years before the river would be forced to take another cause. They assessed that “this was not a problem, because now they were not able to irrigate any land at all. After the river changed its course, probably to one of the flood channels, they would build smaller a bund and still be able to irrigate.” Unfortunately a large flood in the second year made the soil bund inoperable.

In spate irrigation the concept of infrastructure and the associated notions of permanency over the relatively long engineering life of permanent structures need to be re-considered. 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 that reductions in farmers labour involved in the frequent re-building of intakes are delivered. This approach is closer to the traditional system of managing spate irrigation and also links better with existing water allocation rules, disruption of which affects the degree of solidarity among the water users.

9.3.2 Broader livelihood and environmental impacts

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

- Poverty alleviation for a large number of households, who cultivate relatively small spate-irrigated areas as owner-operators and sharecroppers, derived from improved agricultural production and livestock activities.
- Improvement of food security in terms of number of months that farming households can satisfy their food consumption in normal years.
- A multiplier effect because more money enters the local economy due to the involvement of local labour force, craftsmen 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 due to increase of cropped area and 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 due to higher incomes from spate-irrigated agriculture and livestock keeping.
- Reduction in the cutting of trees as the need to earn an additional income from the sale of fuel wood or charcoal decreases due to higher incomes from spate-irrigated agriculture and rearing livestock.
- Reduction in the cutting of trees and shrubs as fewer less or no trees are required for the frequent reconstruction of the traditional diversion structures and any other irrigation infrastructure.

Spate irrigation often 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 also have one or more sources of income from livestock keeping 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 on only on the direct economic benefits derived from agricultural production, but also on social and environmental benefits that may be obtained. It is not always easy to quantify the potential social and environmental benefits of various options. As a minimum they should be given scores in accordance with the probability that these benefits would be achieved and project assessments should use these rankings in selecting the preferred options. In addition it maybe 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 systems 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 support 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 be the "without project scenario" in an economic analysis, a social assessment of two years of drought in Balochistan 1998–2000, based on Qazi (2001), is summarized in Annex 6.

10. Water diversion and control structures in spate irrigation systems

10.1 INTRODUCTION

10.1.1 Background and approaches to design

Spate irrigation is well developed at most of the locations where it is practised. The irrigation infrastructure, patterns of water distribution and arrangements for operating and maintaining systems have evolved over time, to suit the local conditions. Irrigation practices vary between systems and regions and only a summary of the more common features is given in this chapter. Detailed descriptions of a wide range of traditional spate irrigation systems can be found in the key references listed at the end of this chapter and also at the "Community Spate Irrigation" web site[10].

Traditional diversion and water distribution structures often seem crude at first sight, but they enable water to be diverted from uncontrolled ephemeral rivers using only local materials and indigenous skills. When multiple traditional intakes are used along a wadi a relatively high water diversion efficiency can be achieved overall. The principal disadvantage of traditional diversion methods is the excessive inputs of labour needed to rebuild the intakes and the other water control structures that are frequently, sometimes by design, damaged or scoured out by flood flows.

Relatively sophisticated[11] and costly diversion structures, linked to new canal systems, have been introduced in Yemen and Pakistan and Eritrea to modernise and improve the performance of existing traditional systems. These well-intentioned engineering interventions were designed to reduce or eliminate the need for the frequent reconstruction of intakes and in some cases to increase the volumes of water that could be diverted. However, these have often failed to produce the benefits that were expected.

The disappointing performance of many of these systems has been variously attributed to:

- Failures to achieve an expected increase in irrigated area due to over-optimistic assumptions about water resource availability and the water diversion efficiencies that can be achieved with rapidly varying spate flows and manually operated control gates.[12]

- An increased inequity of water distribution, resulting from the construction of permanent diversion structures at the head of spate systems, which gave the

[10] http://www.spate-irrigation.org/librar/librarhome.htm

[11] When compared with traditional structures

[12] In some cases this was a result of comparing the diversion efficiency of well designed permanent gated diversion structure with the much lower efficiency obtained with traditional intakes in floods. A permanent gated intake and the combined diversion efficiency of the many independent traditional intakes that form most systems should be compared over the whole range of flows, including the easily diverted low flows that make up a significant part of the annual flow volumes in many spate schemes. In other cases over optimistic assumptions of increases in cropped areas following modernisation may have been influenced by the need to justify large donor driven projects with conventional cost/benefit criteria. In Yemen there is some evidence that increased abstraction of low flows upstream from new intakes in modernised systems has reduced the flow volumes available for diversion and the hence the areas that could be irrigated from the new facilities.

upstream farmers control over a large proportion of the available flows, to the detriment of downstream irrigators.
- Serious command problems due to high rates of sediment deposition on the fields and canals.
- Unrealistic assumptions concerning levels of operation and particularly the maintenance, mostly canal de-silting, required to keep conventionally designed irrigation networks running in spate systems.

This is due in part to a development approach that focussed on relatively conventional engineering solutions. Experience has shown that if they are to be successful interventions in spate schemes need to be based on a sound understanding of the social and institutional strengths and the simple technologies that are used, that have enabled many traditional systems to function successfully over centuries. To be successful the minimum requirements for engineering inventions designed to improve farmer-managed spate systems are that they should:

- Be easy for farmers to operate and not require the large inputs of labour or other resources to maintain.
- Prevent large and uncontrolled flood flows from damaging canals and field systems.
- Distribute water in line with accepted rules and rights, while providing flexibility to accommodate future changes in water distribution and cropping. They should also ensure an appropriate balance between the needs of different water uses and users, (agriculture, drinking water, downstream users etc).
- Continue to function with high rates of sedimentation on the fields and canal beds.
- Cope with frequent and sometimes large changes to the levels and alignments of unstable river channels resulting from large floods.

While many of these features were being promoted in spate improvement projects nearly twenty years ago[13], providing them in medium and large scale spate schemes at an acceptable cost continues to challenge designers, irrigation engineers, aid agencies and donors.

Improvements requested by farmers are usually aimed at reducing their excessive maintenance burden, through provision of more robust and more permanent diversion and water control structures. As spate systems are often already diverting a substantial proportion of the annual flow volumes and are generally producing low value subsistence crops the economic returns from investments in new diversion and water control structures may be quite small. The engineering challenge is thus to provide affordable improvements to the existing infrastructure, that are compatible with the requirements listed above. Where engineering improvements are justified by returns from subsistence cropping, only low cost improvements, that almost inevitably have a short life and significant ongoing maintenance requirements, are feasible. This is not always a disadvantage in spate irrigation, as these characteristics provide the flexibility to adjust to a rapidly changing physical environment.

Where improvements can be justified from a wider range of benefits, such as poverty alleviation, improved resilience to cope with droughts, or enhanced re-charge of shallow groundwater aquifers, it may be possible to justify an increased level of expenditure. More durable better-engineered structures, with lower maintenance requirements can then be considered. Where spate irrigation is being introduced in new areas farmers will

[13] Silva and Makin, 1987

probably not have the traditional skills that are needed to manage spate flows using traditional structures and simple, easily operated permanent gated intakes and canal water control structures may be needed.

There is no single “silver bullet” approach to the design of improved spate systems. Specific requirements vary widely between and in some cases within, schemes.

10.1.2 Importance of sedimentation

Management of sedimentation is a key factor in spate irrigation. Spate flows usually carry very high sediment loads, which can exceed 10 percent by weight during floods. This is two or more orders of magnitude larger than the sediment loads encountered in most run of river perennial irrigation systems. The sediment load transported in a wadi consists of coarse sediments (sand, gravel and cobbles) and in some cases boulders, found in the wadi beds and finer sediments (silts and clays) that are eroded from the upstream catchments. The fine sediments usually represent most of the annual sediment load and are transported in suspension along the wadis and through the canals to the fields, where they settle. Farmers welcome sediment deposition on the fields as it provides fertility and builds up deep soils with a good water-holding capacity. Spate schemes “grow” their own soils, enabling crops to be grown where the underlying soils are unsuitable for irrigation. The disadvantage is that sedimentation results in command levels rising over time.

The coarser sediment fractions that are diverted from wadis settle on the beds of the upstream reaches of flood canals, which will also rise over time unless the sediment deposits are removed by frequent de-silting.

Traditional systems are able to cope with sedimentation. The fields and canal beds move up together, while the failure of the intakes during large floods limits the entry of coarse sediments to the canals. When necessary, traditional intakes can be easily extended or reconstructed further upstream, to re-gain command over rising field levels. Sediment management becomes critical when permanent diversion structures are used, as in general these are designed to have a relatively long life and cannot be moved. Permanent intakes have to be designed to limit the diversion of the coarse sediments that will settle in canals and also to provide sufficient command to cope with the anticipated future rise in field levels.

10.1.3 Irrigation Infrastructure

The engineering structures involved when spate schemes are improved can be described under three headings:

- Diversion and river training structures
- Canals, flow division and control structures, sediment control structures, escapes and drains
- Field structures

The rest of this chapter is structured around these headings. In each case traditional structures are described first to provide the background to a discussion of low cost improvement options and higher cost more permanent structures. Specific recommendations on engineering issues are drawn together in Chapter 12. Annex 4 discusses some of the more technical aspects of the design of diversion and water control structures and sediment management strategies.

10.2 DIVERSION AND RIVER TRAINING STRUCTURES

Intakes in spate systems have to divert both low flows and spate flows, delivering water to canals at sufficiently high level to ensure command over the irrigated fields. They need to prevent large uncontrolled flows from entering canals, so as to minimise damage to channels and field systems and also limit the entry of the very high concentrations of coarse sediments that are carried in floods. These requirements have to be achieved in unstable rivers, characterised by occasional lateral movements of low flow channels within the wider wadi cross sections, bank cutting and vertical movements of the river bed caused by scour and sediment deposition during floods and flood recessions. Intakes must also function over the longer term with rising irrigation command levels caused by sediment deposition on the irrigated fields.

Traditional intakes and their modern replacements can both fulfil these functions, although by different means and with large differences in cost and maintenance requirements.

10.2.1 Traditional intakes

Traditional intakes can have two basic forms:

The first type is usually found in upstream wadi reaches where the bed slopes are steep, bed materials are coarse and water velocities in floods are very large. They consist of spurs constructed from earth, gravel or brushwood, or a combination of these materials, which extend out into the wadi bed to intercept the low flow channel, heading up and diverting flows to an un-gated canal intake, see Figure 10.1.

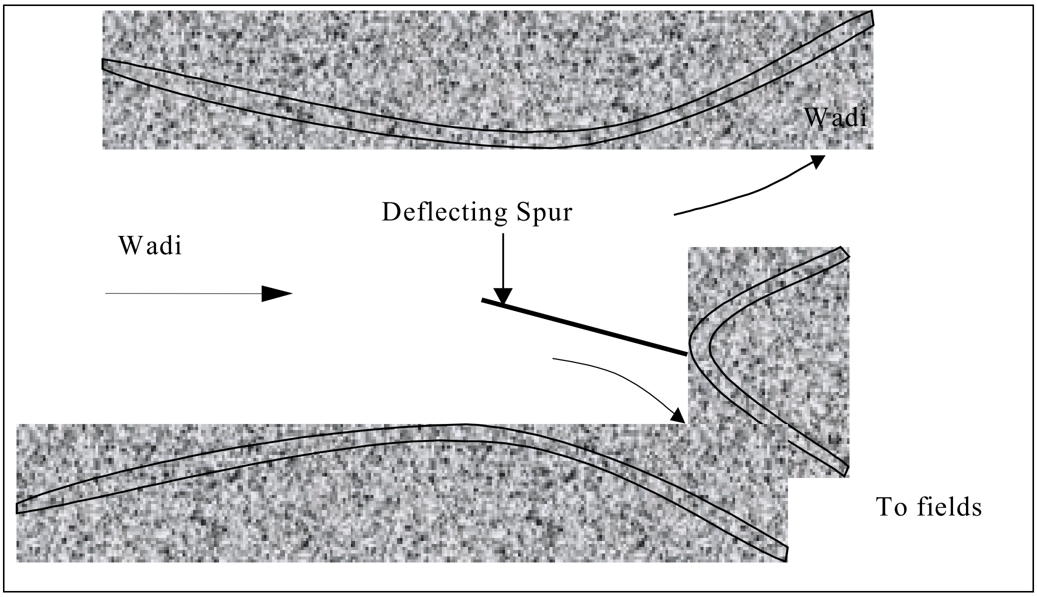


Figure 10.1 Deflecting Spur

Deflecting spurs at intakes in Ethiopia, Yemen and Pakistan are described in Box 10.1.

Box 10.1 Traditional deflecting spur spate intakes

The picture below shows a spur intake viewed looking upstream from a small canal diverting water from a sand bed spate river located in southern Ethiopia. The spur, well located at the outside of a bend where it intercepts the low flow channel, is constructed from tree trunks driven into the wadi bed, woven branches and brush wood and river bed sediments.

Figure 10.2 Traditional spate irrigation intake in Ethiopia

The second example shows a larger traditional intake constructed from cobbles and gravel reinforced with brushwood, located at the outside of a bend of major wadi in the Yemen Tihama Plain bordering the Red Sea. Although a "new" permanent irrigation intake was constructed some km upstream in the 1980s farmers continued to use this and other traditional intakes along the wadi to abstract water from the larger floods that pass over the "new" upstream diversion weir.

Figure 10.3 Traditional spate irrigation intake in Yemen

The third photograph shows a spur type intake constructed at the outside of a river bend, from river bed sediments scraped up by bulldozer in a spate river in Pakistan. Note the fine sediment deposits in the intake channel.

Box 10.1 Traditional deflecting spur spate intakes (continued)

Figure 10.4 Traditional spate irrigation intake in Pakistan

Although the three examples encompass intakes constructed in different ways, in wadis with different sizes and flow characteristics and at widely separated locations, they share many common features:

- They are located at the outside of wadi bends, where the deep water channel forms in floods and the low flows are channelled in flood recessions.
- They consist of a low spur that is extended into the wadi to intercept the low flow channel.
- All are constructed from locally available materials and can be maintained and re-constructed by farmers without significant external support. In the last example bulldozers are available to farmers at subsidised rates.

While the different forms of construction result in varying degrees of durability, all the intakes are likely to be damaged or completely swept away by the larger floods.

The second type of diversion consists of a large bund constructed from river bed material that is built right across the river bed, which diverts all the wadi flow to a canal or canals, until it is overtopped and scoured out by large floods, Figure 10.5.

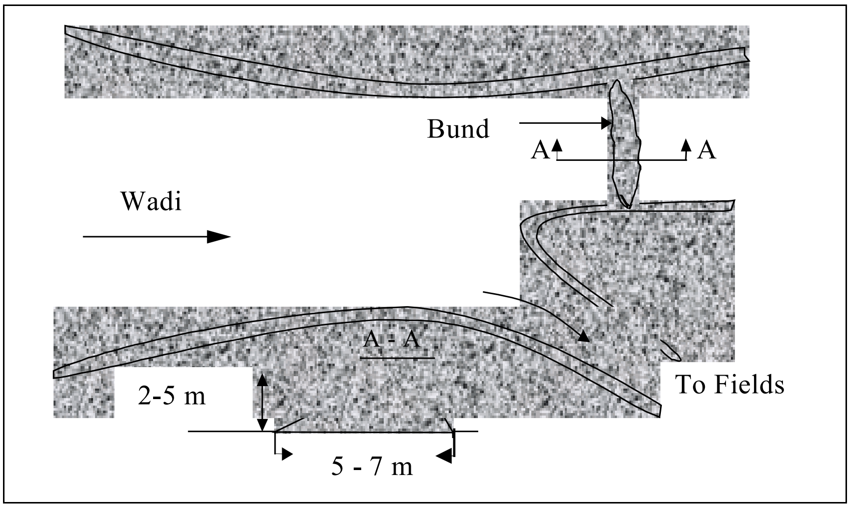


Figure 10.5 Diversion bund intake

These structures tend to be constructed in the lower reaches of wadis, where the bed slopes are flatter, water velocities are smaller and the bed materials are finer. Traditionally, structures of this type are constructed using draught animals and scraperboards, see Figure 10.6.

Figure 10.6 Bund construction with bullocks and scraper boards, Eritrea

This method of construction is not feasible with the coarse bed sediments found at upstream diversion sites, but bulldozers can be used to construct diversion bunds from the wadi bed materials found at both upstream and downstream locations.

In Pakistan some very large structures of this type are used. (See Figure 8.2 in Chapter 8). Over time sediment deposition upstream from diversion bunds raise the upstream riverbed level, increasing the probability that a bund will overtop and scour out. There is always danger with this type of diversion of diverting very high flows into the flood canals, which can result in the whole river being permanently diverted through the irrigated area, creating enormous damage to canals and field systems. Bunds are often deliberately breached by the farmers in large floods to prevent this happening.

In Pakistan large bunds are also constructed at the downstream end of degrading river reaches to halt and reverse a general lowering of river bed levels that can cause large areas to go out of command. In these systems sedimentation is being actively managed by farmers to restore the upstream river bed levels to an elevation that allows upstream intakes to function.

In summary the advantages of traditional diversion structures include:

Flexibility – the riverbed topography and the alignment of low flow channels may change after medium or heavy floods, but the location and layout of traditional intakes are easily adjusted to suit the changing riverbed conditions. They can also be extended or moved upstream when sedimentation on the fields or in the canals starts to raise command levels.

Appropriate and low cost – traditional intakes are constructed from local materials using indigenous skills and apart from environmental problems resulting from unsustainable use of trees and brushwood, can be maintained indefinitely by irrigators without outside support.

Relatively efficient – when numbers of traditional intakes are used along a wadi relatively high overall diversion efficiency can be achieved. Large floods frequently destroy intakes located at the heads of spate schemes, but the flood peak discharges reduce as the flood passes down a wadi and it is often possible to divert water at downstream intakes, even when upstream intakes have been destroyed. Although very high flood discharges occur a large proportion of the annual run off in most wadis flows in small floods recessions and base flows, discharges that can be effectively diverted by traditional intakes.

Limit diversion of high flows and high sediment loads - The failure of diversion spurs at high wadi flows lowers the water level at the canal intakes, reducing the discharges that are diverted. Failures also limit the diversion of very high concentrations of coarse sediments that are transported in spate flows and will settle in and block the upstream sections of canals. This also applies, but to a lesser extent, to low diversion bunds. If the bunds are high very large flows will be diverted to canals before they fail by overtopping, or deliberate breaching.

However there are some major disadvantages associated with traditional diversions. The most important is the enormous input of labour needed to maintain and reconstruct intakes that are frequently damaged, or completely washed out by large floods. One estimate from Eritrea suggests that about 80 percent of the labour needed to operate a traditional spate irrigation system are devoted to maintaining and repairing intakes. One of the justifications for the large World Bank supported spate irrigation improvement projects carried in the Yemen since the 1980s was that out-migration of male labour was making the traditional systems unsustainable as the labour needed to keep the systems functioning was no longer available. A second disadvantage is that although a relatively high overall diversion efficiency can be obtained with multiple intakes, it is not always possible to divert water where it is needed. For example, a series of very large floods may destroy all the upstream deflectors along a wadi, making upstream diversion impossible until the intakes are repaired. Conversely if only small floods occur then these will either all be diverted at the upstream intakes, or "lost" to seepage into the wadi bed before the flows reach the downstream diversion sites.

10.2.2 Low cost improvements to traditional diversions

Modest improvements to traditional intakes minimise changes to existing canal systems and water rights. The basic objective is to reduce the massive labour requirements involved in frequent rebuilding of intakes. Box 10.2 describes some improved traditional intakes developed by farmers in Yemen, which contain many of the features needed to reduce maintenance requirements to an acceptable level.

Box 10.2 Farmer improved spate irrigation structures in the Hadramawt and Shabwa Governorate in Yemen

Al-Shaybani (2003) describes diversions, canal intakes, side weirs and canal escapes used in some of the well-developed traditional systems in Southern Yemen.

In wide wadis a spur type diversions similar to but stronger than the types described earlier are used. A spur is constructed from interlocking stones set on a deep foundation. The height reduces from 1 to 1.5 m at the canal entrance to only a few cm at the centre of the wadi. The foundation is deep and wide and the spur is constructed with a triangular cross section.

Figure 10.7 Partially breached diversion spur in Wadi Beihan, photographed from the wadi, looking towards the canal intake

If the wadi is narrower, say 50–60m, a weir spanning a wadi may be constructed from interlocking stones. (This is an alternative to a diversion bund). The weir is set on a substantial foundation between 3-4 m wide and set deep enough to be based on a suitable hard foundation. The weir is formed from two walls of stones, with a sloping upstream face, a stepped downstream face. The gap between the walls is filled with sand and small stones. The top of the structure is closed using large stones and sometimes sealed with concrete.

Box 10.2 Farmer improved spate irrigation structures in the Hadramawt and Shabwa Governorate in Yemen (continued)

The stepped downstream face dissipates energy when the weir is overtopped and large stones are placed on the downstream wadi bed to control scour.

Figure 10.8 Diversion Weir with a stepped downstream face

Canal entrances are formed by two stone structures, Algama, see Figure 10.9 Algama are conical stone structures, with a circular base of 3–4 m in diameter. They are constructed by digging a circular foundation about 2 m deep and lining it with large stones and filling in the gaps with smaller stones. The rest of the structure is then built up with the centre being completely filled with small stones and cobbles. The height is usually 2–3 m and the side slope ranges between 35° to 40°.

Figure 10.9 Canal head with Algamas forming the left and right sides of the canal entrance

Box 10.2 Farmer improved spate irrigation structures in the Hadramawt and Shabwa Governorate in Yemen (continued)

Aglamas may also be constructed in rows to protect sections of vulnerable wadi bank. They are also used to provide hard points at the end of lowered sections of the wadi side of a canal bank forming a rejection spillway.

Rejection spillways are usually located in the first 100 m of the canal and are placed between two Aglamas that define the overflow section and prevent large flows from scouring out a long section of canal bank. The spillway section has an elevation 0.5 m lower than the canal bank. Farmers may strengthen the overflow section with grass, branches and stones.

Al-Shaybani (2003) reports that in Wadi Beihan the numbers of traditional structures have been decreasing as a result of the introduction of gabions in the area. The farmers became reliant on gabions supplied through an agency and ignored the traditional structures, even though they are claimed to be more effective than the gabion structures in some respects and can be cheaper to construct. Traditional structures can continue to give good service following rehabilitation. Figure 10.10 shows a traditional weir after rehabilitation that included adding a concrete-facing, improved downstream scour protection and abutments extended with gabions.

Figure 10.10 Rehabilitated traditional weir in Wadi Haudramat

The structures described by Al-Shaybani contain most of the elements needed to improve diversion in less developed traditional systems, although these do not necessarily have to be constructed using traditional materials. The “hard” structures at the canal head play some role in limiting the flows admitted to the canal, but more importantly protect the canal head from scour in periods of high flow and provide a strong point to anchor a diversion spur or weir. The rejection spillways and other escapes located along the canals, are essential features in these systems in protecting the canals from excessive flows.

There are many options for improvement, depending on the site conditions and the available resources and farmers’ preferences.

Use of Bulldozers

The simplest means of reducing the labour required to construct bunds or re-build traditional diversion spurs is to provide access to bulldozers[14]. Suitable machines can work in the wadi bed during flood recessions, see Figure 10.11, to re-build spurs damaged by large floods.

Figure 10.11 Bulldozer repairing a traditional diversion spur during a flood recession - Wadi Rima in the Yemen in the mid 1980s

Bulldozers can rapidly construct larger and more durable diversion spurs and also more substantial and higher diversion bunds, than is feasible with traditional methods. As the more durable diversions continue to function at higher wadi discharges than traditional structures, it will often be necessary to provide an intake control at the head of the canal to limit the maximum discharges that are admitted to the canals.

Bed sills (bars)

The use of gabion sills to stabilise a wadi bed at a potential intake location was tested in pilot trials carried out in the Yemen over twenty years ago. These trials demonstrated that a bed sill does little to control the location of the low flow channel at an intake when wadi beds are aggrading. Gabions, even when protected by a surface skin of concrete, had a very short life at upstream sites where boulders and cobbles were transported in floods. Bed sills (or bed bars) have been designed to prevent the lowering of the wadi bed in a recent project in the Yemen. The preferred material for bed sills is mass concrete, which can be cast into excavated trenches.

The use of a bed sill is only likely to be beneficial in wadis where retrogression of the wadi bed is perceived to be the main problem.

[14] The relative success of programmes that provide bulldozers to spate irrigators at subsidised rates is described in Section 8.1.3 of Chapter 8.

More durable diversion spurs

The direct replacement of traditional diversion spurs and bunds with more robust structures constructed from gabions, masonry or concrete, have often not proved to be very successful as they were not designed to resist scour or overturning forces generated in large spate flows. For example, simple rubble masonry walls constructed in wadi beds in Northern Ethiopia to increase the durability of traditional division spurs rapidly scoured out in large floods. In Eritrea a substantial gabion spur was constructed to replace a traditional diversion structure at the head of a major spate system. This was damaged and eventually largely destroyed by floods, but not before it had diverted large uncontrolled flows through the irrigated areas, causing widespread damage to the bunded fields and irrigation infrastructure.

However the examples from Yemen illustrated in Box 10.2 show how more durable diversion spurs constructed on deep foundations can be successful, when allied with measures to restrict flows entering canals. Gabions, rubble masonry or reinforced concrete construction could be used to construct this type of structure, depending on local conditions and relative costs.

Improved diversion bunds

Improved bunds can be constructed using a bulldozer. More permanent structures have to be designed with overflow sections, i.e. as a weir and include appropriate energy dissipation arrangements, as discussed later.

Earthen bunds can be improved by incorporating a low section. This helps to ensure that when the bund is first overtopped the initial breach occurs away from the canal head. Farmers often choose the location to minimise damage and to reduce the possibility of the wadi diverting to a new course leaving the intake outflanked.

Controlling the flows admitted to canals

This involves permitting flows up to the design capacity to enter a canal and then restricting higher flows. The most basic control is a head regulator structure without gates. In its simplest form this can be a rectangular opening with two side walls constructed of suitable materials (masonry, concrete or gabions) and will be most effective where the maximum flood levels in the wadi are relatively low. The next development is to design the head regulator to act as an orifice once the design flow is reached, by providing a breast wall over the opening. The bottom of the breast wall should be at the canal design water level. As the land levels and canals beds will be rising it will be necessary to construct the bottom part of the breast wall in removable panels (i.e. as concrete or steel beams) that can be taken out to compensate for rising levels. Breast walls and high abutments are most needed when the wadi channel is confined and flood levels are high. Gated intakes and rejection spillways located near the canal head provide further levels of protection. These are discussed later.

Basic Gated Intakes

Gated intakes provide a capability to regulate the flow into a canal. The gates should be the largest possible size suitable for manual operation, since intermediate piers in the head works increase the hydraulic losses and catch trash during floods. Ideally, the gate openings should be wide enough to pass substantial trash since any blockage will cause a possibly critical loss of water for the farmers. Vertical gates will usually be used as they are far less expensive to manufacture than radial gates, although they require greater operating effort. Vertical gates greater than about 2 m in width are inappropriate for manual operation whereas manually operated radial gates can span up to about 5 m.

Usually a breast-wall is provided above the gate, with the bottom of the breast-wall being set at the upstream water level required to give the design flow. This limits the maximum flow when the gate is open and minimises the size and weight of the gate. However provision for rising command levels should be made as discussed above.

Operations guidelines often recommend that canal intake gates are closed during large flood peaks to exclude water carrying very high sediment loads from the canal system. However, farmers are usually reluctant to accept any closure as it represents lost water. Without power assistance it is anyway often not feasible to close and open gates within a short period when high flows occur. It is unwise to assume that manually operated gates will be closed except during the largest flows, when the large flows entering the canals threaten serious damage to the water distribution infrastructure.

Gated intakes are obviously more expensive than un-gated structures and should thus have a long working life. It is prudent to design gated intakes with a generous provision for a future rise in command levels, where necessary providing a drop structure in the canal downstream of the intake. This will help ensure that a gated intake will continue to function as the field and command levels rise over time. The drop will progressively become buried as the fields and the canal beds rise.

Rejection spillways

Farmers sometimes construct rejection spillways in traditional systems, see Figure 10.12

Figure 10.12 Side spillway constructed by farmers, Wadi Rima Yemen

In improved systems they will often be required to limit the flows diverted to canals. The rejection capacity is normally provided as a side spillway in the first part of the main canal, where water can be easily passed back to the wadi. The effectiveness of the spillway is in proportion to its length. The spillway will be more effective if a further flow control structure is provided on the canal just downstream of the spillway, as water level changes at the structure will be much more sensitive to excess flow than in an open channel. An orifice control would be the most effective at causing rejection, with the top of the orifice being set at spillway crest level.

10.2.3 New permanent diversion structures

Diversion of spate flows in traditional systems is usually carried out at many locations along a wadi, with intakes given priority for diversion according to more or less complex water rights agreements. Multiple intakes provide an effective solution where the cost of each diversion structure is low and each diversion supplies a relatively small canal system with manageable flows. If substantial improvements to diversion arrangements are envisaged, then the cost of making these improvements at numerous intakes becomes prohibitive and the usual practice has been to provide a limited number of major diversion structures, often only one, serving new large canals that connect to the existing traditional canals. A major disadvantage of the single new intake approach is that it gives the upstream irrigators control over diversion of a large proportion of the annual flows and this led to an increase in the inequity between upstream and downstream water users' access to water[15]. Also, mostly for cost reasons, the diversion capacity of new intakes has tended to be less than the combined capacity of the traditional intakes. There are many examples of farmers in "improved" systems re-activating their traditional intakes in order to capture the flood flows that pass over the weirs of a new single permanent diversion.

We suggest that systems containing numerous self-contained intakes and canals should not be consolidated to receive water from a single diversion point, although some rationalisation may be essential if the numbers of independent diversion structures are to be reduced in order to provide better-engineered and more durable replacements.

Three examples of permanent intakes of differing levels of sophistication (and cost), constructed in modernised or new spate schemes are given below. Design considerations for permanent diversion structures in spate systems are discussed further in Annex 4.

Wadi Rima, Yemen

Figure 10.13 shows the new single intake constructed to supply an existing traditional spate irrigation system in the Wadi Rima in Yemen, in the late 1980s, (Oosterman 1987). The new intake was constructed at the head of the existing irrigated area, close to the mountain front and near to the site of the most upstream of the existing traditional intakes. At the diversion site the natural wadi width is constrained by rock outcrops and is fairly narrow. The intake consists of a raised weir and a canal intake and low-level sluiceway located on the north bank. The intake supplies a feeder canal that runs along the north side of the wadi, passing water to the traditional canals where it crosses them. A feeder canal running along the South bank is supplied by a siphon running underneath the wadi.

[15] This has often been a result of the way that systems are being operated in response to pressures from powerful local interests, rather than to inherent technical deficiencies in the water distribution arrangements. An equitable distribution of flows would have been possible in some of these new systems where a sufficiently large diversion capacity was provided. In some cases this would have required a change to water rights rules based on volumetric allocations and to operation by strong farmer groups or operating agencies that were able to enforce an equitable water distribution. Neither of these pre-conditions turned out to be feasible in many of the systems modernised over the last twenty years.

Figure 10.13 Wadi Rima spate irrigation intake, Yemen

The new system replaced a traditional spate system with many intakes along the wadi, with rotation between canals of base and low flood flows diverted at a single point at the head of the wadi. The main technical features are:

- A relatively high weir was provided to obtain the head needed for effective hydraulic sediment flushing. The 70 m long weir is constructed from mass concrete with a protective layer of stone to resist abrasion from the cobbles and boulders that pass over the weir in spates. The weir crest slopes down towards the canal intake, with a drop of 1 m across the weir crest, to encourage the low flow channel to flow towards the canal. A short submerged bucket-type stilling basin was used.
- The gated under sluice was designed to pass the lower heavily sediment-laden layers of the approaching flows through the structure during floods. The sluiceway was originally intended to operate automatically in floods, but trash accumulations and deposits of fine sediments in the small openings that formed part of the hydraulic actuation system prevented the original system from functioning. The sluice gates are operated manually during floods. Initially trash blocked the intake so a trash screen consisting of vertical steel pipes and horizontal steel cables has been constructed in front of the intake to divert trash over the weir, see Figure 10.15.
- A gated canal intake is aligned with the approaching flow direction, supplying the main canal via a short settling basin designed to trap the coarse sediments before they enter the main canal. The settling basin can be flushed to return trapped coarse sediment to the wadi.

The layout of the north side of the intake showing the under sluice, canal intake, sediment settling basin and the sediment flushing arrangements, from (Oosterman 1987) are shown in Figure 10.14.

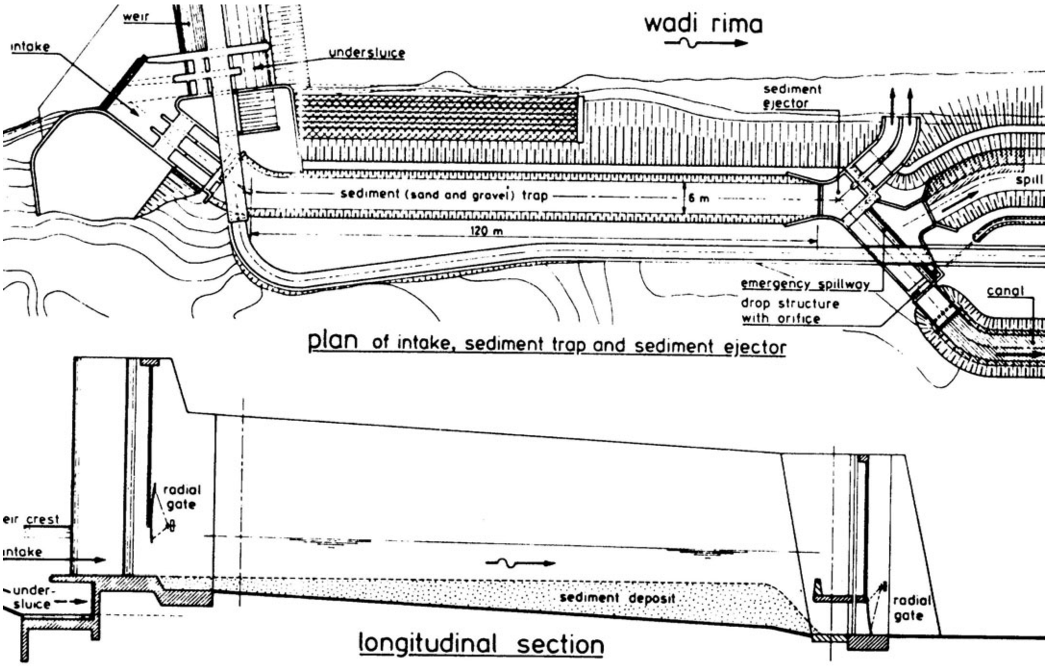


Figure 10.14 Plan of Wadi Rima intake and sediment settling basin.

Following the experience gained during the initial operation of the new intake the designers made a number of recommendations, (Oosterman 1987). These include a recommendation that when there is sufficient width a fusing section (fuse plug) should be incorporated in a weir to provide protection from extreme floods. They suggest that a fuse plug should be designed to fail in flows occurring once every ten to fifteen years. Following the problems with trash encountered at this intake they recommend use of a wide scour sluice, at least 5 m, constructed, unlike the Rima intake, without a breast wall to allow large trash like tree trunks to pass through the structure.

A trash deflector was later constructed from steel pipe and cables, to deflect trash away from the canal intake and towards the sluiceway.

Figure 10.15 Trash deflector, Wadi Rima intake Yemen (2003)

This intake, with the Wadi Mawr example described earlier (Box 2.1 in Chapter 2), represent what are probably the most technically sophisticated intakes that have been developed for spate irrigation schemes. Both were designed to be operated by an irrigation agency rather than farmers. Control over the elevation of the wadi bed and water levels and the location of the low flow channel, are achieved with the sloping weir. This is located at the outside of a shallow wadi bend, with a sloping crest that directs the low flow channel towards the intake. The sediment handling arrangements exclude very coarse sediments via the under-sluice. Gravel and coarse sand is trapped and then hydraulically flushed from the settling basin. Strict control over the operation of intake and under-sluice and sediment flushing gates is required if the structure is to function as intended by its designers.

While there are some excellent technical features incorporated in this intake, the new scheme has suffered from a long running dispute between north and south bank water users. A change in the cropping pattern to intensive banana production in the upstream irrigated areas and the relatively small diversion capacity (15 m^3/s) contributed to interference with the water distribution arrangements and large reductions in water supplies intended for south bank and downstream irrigators. This prompted farmers to reactivate some of their traditional intakes, to divert water from the flood flows that pass over the weir and to construct a new intake and supply canal on the south bank.

Wadi Laba Eritrea

A new intake was constructed to supply a traditional spate irrigation system in Wadi Laba located on the Eritrean Red Sea coastal plain. This is probably the latest major spate-diversion structure to be built with support from an international development agency, (IFAD, with technical supervision from the World Bank). Its design utilised the experience gained from Yemen and earlier farmer operated spate improvement projects in Pakistan. It was intended for farmer operation.

Figure 10.16 shows the diversion structure viewed from upstream. The key features are a canal intake incorporating a curved channel sediment excluder, see Annex 4, a low and to minimise costs, short, concrete weir, with a breaching section or fuse plug that connects the weir to the far bank. The use of fuse plugs is discussed in Annex 4. In summary they enable a substantial cost saving as a weir can be designed to safely pass flows that might occur say once or more every five to ten years, rather than the very much larger extreme floods that are usually adopted for the design of permanent diversion structures. A short settling basin, designed to be excavated by bulldozer, was constructed in the canal head reach. This traps gravels and coarse sands not excluded at the intake. A conduit near the canal head runs under the wadi to supply water from the main canal to the irrigated areas located on the opposite bank of the wadi.

In the picture the canal intake gates and the gated curved channel scour sluice are on the extreme left, the concrete weir is in the centre and the fuse plug extends from the end of the weir to the right hand edge of the picture. The crest level of the fuse plug is higher than the design flood level at the weir end and reduces across the wadi, to ensure that the fuse plug washes out initially at the far bank.

Figure 10.16 Spate diversion structure constructed at Wadi Laba, Eritrea

The system was commissioned in the wet season in 2002, when a major flood, its peak discharge still being a matter of some dispute, washed out the fuse plug. This protected the weir and intake from serious damage, but as the fuse plug was not repaired for some months, water from the later floods could not be diverted and only a very small area was irrigated. Farmers regarded this as a serious failure of the new system, even though the fuse plug had functioned as its designers and the international agencies that supervised the project, had intended.

An obvious lesson from this experience is that the implications of including a fuse plug in a diversion structure must be understood and more importantly agreed, by the farmers or agency that will have to rebuild a fuse plug when it fails. Robust arrangements must be in place to ensure that a fuse plug is rapidly reinstated following a breach.

The fuse plug was repaired for the 2003 wet season and the new intake performed broadly as anticipated, stabilising the wadi approach channels at the canal head, controlling the flows admitted to the canal and excluding large sediments from the canal head reach. The sluice was kept open as much as possible to provide water for downstream south bank irrigators, who were unhappy with the volumes of water supplied by the conduit. It did not prove to be possible to excavate the settling basin as a bulldozer could not work on the wet unconsolidated sediments trapped in the basin, which rapidly silted up. Machines, which can work from the bank, are needed to mechanically excavate the settling basin. As a series of floods may occur within a few days, sediments often have to be removed when the canal is still flowing and before the sediment deposits can dry out.

Haile (2003) gives a description of the earlier traditional system and the experience over the first two years of operation of the new system. While it is still a little early to draw firm conclusions from an intake and water distribution system requiring quite different operational skills to those needed for the traditional systems it replaces, the paper by Haile (2003) draws a number of useful conclusions. Many of these are concerned with institutional issues, particularly the need for more effective participation with farmers in the design and development of spate improvement projects. On the technical performance of the intake he reports that:

- Operation of the intake structure, particularly the sluice gates, in very rapidly varying spate flows is problematical. (This has been observed in many other spate schemes – ideally electrically or mechanically powered gates would be provided, but as in this case they can rarely be justified by conventional cost-benefit analysis as applied in Internationally funded projects.)
- The diversion capacity provided at the new intake may be too small to irrigate the target command area, as the design area was not irrigated in 2003 despite it being a year with very good floods.

Adurguyay Intake, Gash Barka region, Eritrea

The last example is of a basic permanent intake constructed on a small ephemeral sand bed river in Eritrea, in a region where spate irrigation is being introduced to areas that have relied in the past on rain-fed cropping. The river is much smaller than the wadis considered in the earlier examples.

The structure is shown in Figure 10.17. It includes the elements found in conventionally designed river intakes i.e. a raised weir, a gated scour/sediment sluice and a gated canal intake.

Figure 10.17 Adurguyay Intake, Eritrea

The photograph was taken shortly after construction of the intake. It is expected that in future the upstream bed level will silt up and rise close to the crest level of the weir.

Local engineers report that this structure has functioned reasonably well in the first year that it was operated by farmers, offers several advantages over the gabion weirs with un-gated canals that they have used at similar sites in the past and can be constructed at similar cost. The technical problems of diverting water from ephemeral spate rivers reduce as the wadis and their flood peak discharges, become smaller. The introduction of spate irrigation to new areas is best carried out on small tributary wadis.

10.2.4 Bank protection and river training

Bank protection and wadi training[16]

High flow velocities during spates often erode wadi banks, particularly in the meandering middle and lower reaches. The sinuous flow alignments within the wider wadi channel results in scouring and undercutting of wadi banks at the outer curves and sedimentation at the inner curves. This causes meander patterns to develop and migrate downstream. Bank erosion scours out valuable irrigated land and can threaten canals running parallel to the wadi banks, see Figure 10.18.

[16] Much of this section in based on the recommendations made in Camacho (2000)

Figure 10.18 Bank cutting and the development of a meander – Wadi Rima Yemen

Farmers regard their irrigated land as a priceless asset and they give bank protection work a high priority. Brushwood and stone are used to protect vulnerable sections of wadi banks and in some cases low spurs are created by planting lines of shrubs out into the wadi that trap sediments and eventually reclaiming the land that has been eroded. Bank protection using boulders and brushwood in Eritrea is shown in Figure 10.18. It is reported that this form of construction, used for both bank protection and diversion spurs, is becoming unsustainable in the project area due to the over exploitation of trees and shrubs. Farmers have to travel increasingly large distances to collect the material needed.

It is usually impossible to justify protection against damage from large flood events with conventional river training works by applying a strict economic benefit/cost analysis, due to the very high costs involved when compared with the low value of land and the crops that are grown. To be economic, bank protection works have been designed to protect against floods with a relatively small return period, but these were swept away when larger floods occur. Some localised civil works may be justified where villages, bridges or roads need to be protected, but even then localised river training works can soon become outflanked or compromised by changes in the channel alignments in the untrained upstream sections of a wadi.

Figure 10.19 Bank protection using brushwood and boulders – Wadi Laba Eritrea

Nevertheless, something has to be done to check erosion and reclaim irrigated land that has been scoured out. Where canals run parallel to a wadi, protection is often needed to safeguard the water distribution system. "Low cost" river training and bank erosion control schemes using boulders or gabions are shown in many river engineering handbooks. For wadis, substantial structures are needed due to the very high flow velocities and deep scour depths that will occur.

Camacho (2000) suggests the use of natural vegetation for bank protection as a more sustainable and lower cost option than more conventional river training works in spate irrigated areas. Vegetation reduces local flow velocities, causing sediment to be deposited in front and behind of a vegetative barrier. The coarse sediments and silt transported during high and medium flows mixed with vegetative debris (trash) can build up to form natural protective structures. When established, vegetation can withstand normal floods and if damaged by a large flood will sprout again and regenerate. The difficulty is in establishing vegetation where it is needed, as natural vegetation occurs where the flow velocities are low and seeds are deposited and covered with enough sediment to cause germination. Unfortunately, these locations are not where bank protection or wadi training spurs are required.

Vegetation can be established at high flow velocity locations by planting cuttings deep and giving them some initial protection against scour and wash out. Some suggestions of how this might be achieved are given in Camacho (2000). Vegetation would be planted in good wet soil at the bottom of a ditch, backfilled with graded material ranging from sand immediately above the soil, through gravel and shingle to large boulders on top. Bank protection could be achieved by armouring the most exposed parts of the outer curves where erosion was taking place with dense vegetative cover grown under the protection of a provisional retaining wall constructed from wadi boulders. Wadi training would be achieved using short vegetative spurs. Figures 10.20 to 10.22 show preliminary designs, (Rouchiche, quoted in Camacho (2000)). It may be necessary to improve the level of scour protection indicated in these sketches.

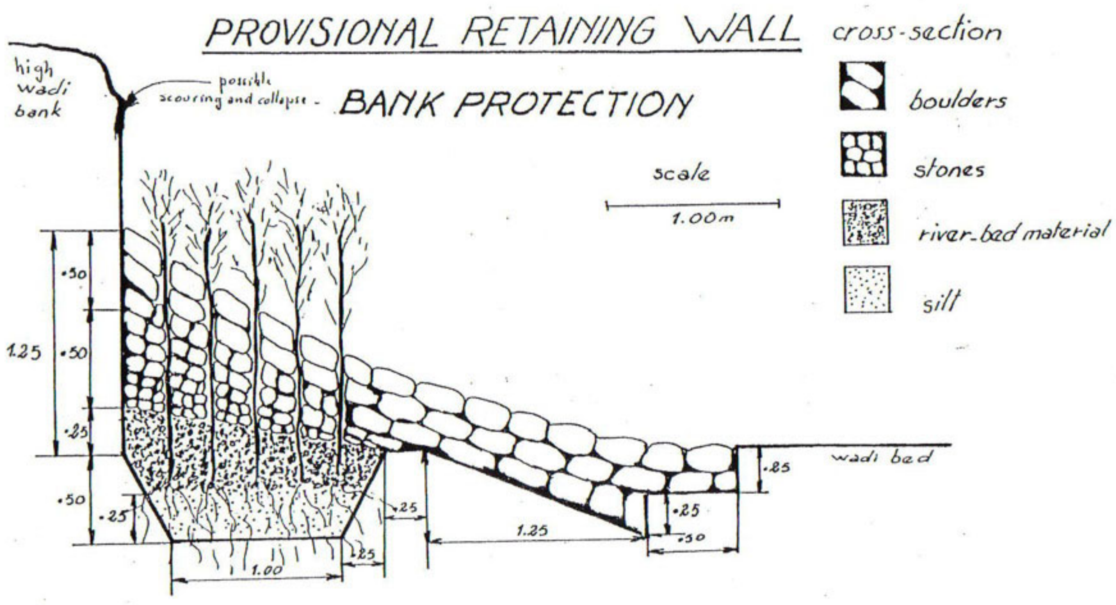


Figure 10.20 Bank protection using natural vegetation

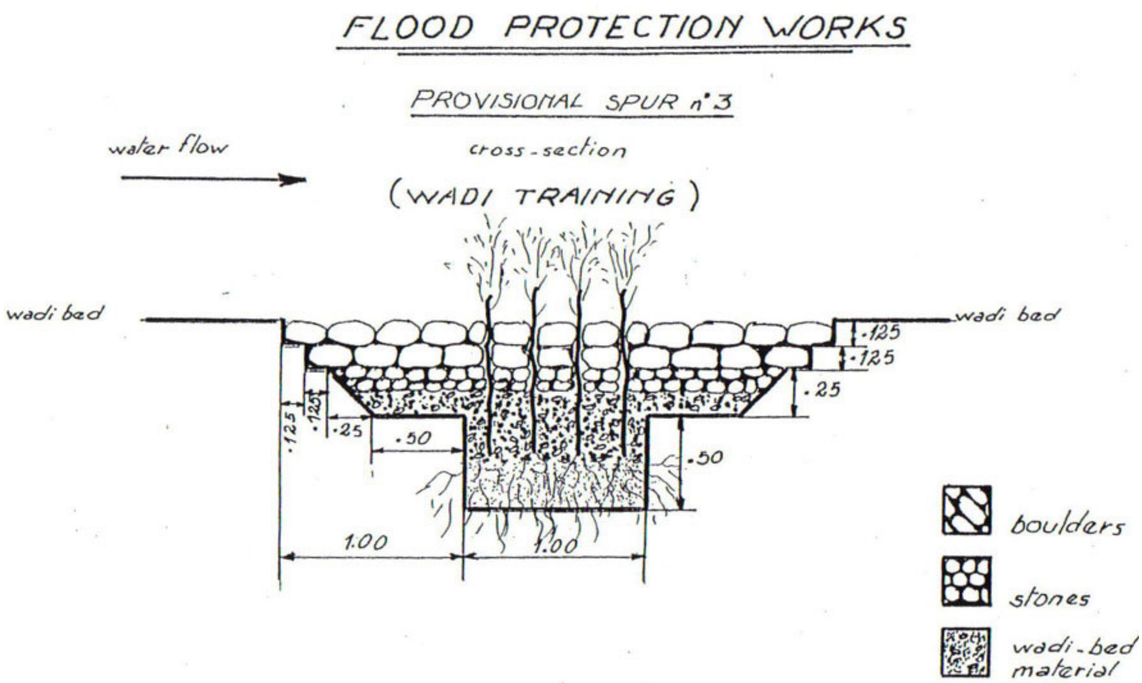


Figure 10.21 Spur using natural vegetation

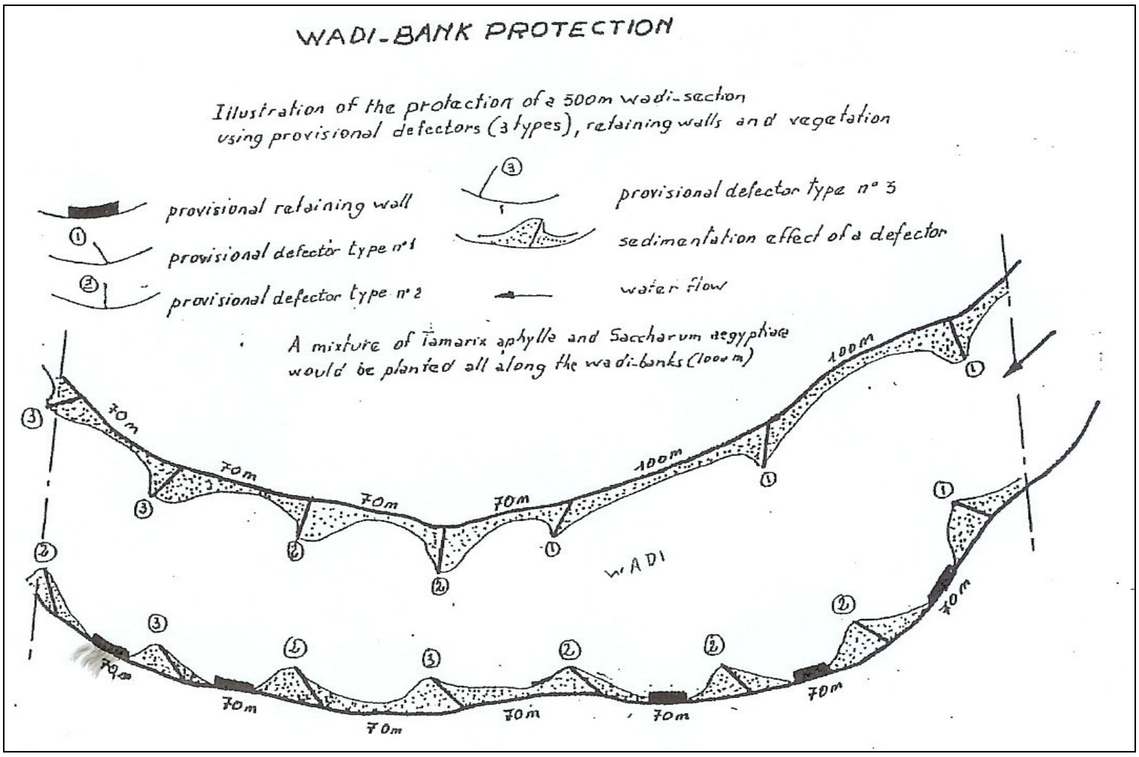


Figure 10.22 Proposed bank protection using retaining wall and spurs with shrubs

Controlling wadi bed levels

Wadi beds can be significantly lowered during the passage of large floods and it is not unusual for traditional intakes to be left stranded above the new scoured bed level, making it impossible to divert water. The usual response is to re-locate the intake, or to extend a diversion spur upstream to regain command. Where this is not possible it is necessary to install one or more low check structures that trap sediments and raise the bed levels. It would usually be beyond the capacity of farmers to construct structures that span a wadi and are robust enough to survive spate flows. Providing engineered structures (low overflow weirs constructed from concrete gabions or rock) to control bed levels are an option, but will often be difficult to justify in small spate schemes growing subsistence crops. In Pakistan, where bulldozers are available to farmers at subsidised rates, some very large bunds have been constructed to regain command in degrading wadi sections. While these sometimes fail, this approach seems to be effective and affordable in the context of the economics of spate systems.

10.3 SPATE CANALS AND WATER DIVISION STRUCTURES

In traditional spate irrigation systems, spate flows are diverted to short, steep canals. Larger canals may split into two or more branches to reduce flood discharges to manageable flow rates, but there are usually no secondary or tertiary distribution systems. All the flow in a canal is diverted to a group of bunded fields, by an earthen bund that blocks the canal. Water is passed from field to field until all the fields in command have been irrigated. The canal bund is then broken and the process is repeated at a bund constructed further down the canal at the next diversion point. Once the bund is breached the canal water level drops below the level of the field off-take, preventing further diversion until the bund can be re-built. The order in which fields are irrigated and depth of irrigation are controlled by more or less complex water rights agreements, as described in Chapter 7.

The objective is to divert the maximum amount of water to the fields in the short time period, often only a few hours that significant spate flows occur. Water conveyance systems in spate schemes need very much larger canal capacities per unit area served than those in perennial irrigation schemes.

10.3.1 Traditional canals and water control structures

Traditional canals in spate schemes are usually constructed without drop structures and are far steeper than conventional canals used in perennial irrigation systems. Canal slopes similar to the bed slope of the wadi from which water is diverted and much steeper than canals designed by irrigation engineers in conventional irrigation systems are usual, see Box 10.3.

Box 10.3 Traditional canal slopes

Traditional canals are usually constructed at the prevailing land slope and rarely incorporate the drop structures used in conventional canal systems to reduce the slope and flow velocities. Traditional canals rarely seem to suffer from the excessive sedimentation problems observed in the canals of some modernised spate systems and although quite high flow velocities are generated, neither do they seem to suffer from widespread scour problems. This is because spate canals flow at their maximum discharge for very short time periods during flood peaks. Most of the time the canal discharges are much lower than the maximum. Canals also carry high sediment loads. Thus while there may be some erosion of the canal bed and banks when the flow in the canal is large, there is little chance of serious scour problems occurring.

Bed slopes of traditional canals in the original (before modernisation) Wadi Zabid system in Yemen are reported in FAO 1987:

Canal	Maximum capacity (m^3/s)	Average bed slope (m/km)
Mansury	40	3.8
Rayyan	60	3.7
Bagr	40	3.7
Gerhazi	50	3.9
Mawi	60	4.8

The canal slopes are about half of the slope of the wadi bed at the upstream diversion site and are very much steeper than the canals in the “new” system. These were designed with slopes derived from conventional perennial irrigation canal design methods and had slopes of only 100–300 mm per km – they rapidly silted up.

Canal design methods that account for the very high incoming sediment loads are needed to design new spate canals. The Chang (1985) canal design method, recommended in Annex 4 for use in cases where the incoming bed material sediment concentration and canal bed material size grading can be estimated, predicts slopes only a little less than those tabulated above.

The upstream reaches of traditional canals often resemble natural wide, shallow wadi channels, with beds formed from very coarse sediments. The size of the bed sediments reduce rapidly as coarser sediments settle out in the upstream reaches. The middle and lower reaches of upstream canals and also canals diverting water from lower wadi reaches typically have sand beds. The lower reaches of established canals may have stable armoured beds and flow between well established banks that are protected from high water velocities by natural vegetation. Traditional canals rarely seem to suffer from the excessive sedimentation seen in some of the "modernised" spate systems, although some sections may be susceptible to scour and overtopping.

Several types of water control structure are found in traditional canals, ranging in sophistication from the simple earthen bunds used to head up and divert water from a canal to groups of fields, to more "engineered" structures such as the rejection spillways, flow division structures and drops. Examples of a canal diversion bund that has been breached to pass water further downstream, are shown in figures 10.23, viewed from upstream and Figure 10.24, viewed from downstream. A more sophisticated farmer-constructed water control structure is shown in Figure 10.25.

Figure 10.23 Breached canal diversion bund, Wadi Zabid, Yemen in 1980

Figure 10.24 Breached canal diversion bund, Wadi Zabid, Yemen in 2003

Figure 10.25 Traditional drop structure, Wadi Zabid, Yemen

10.3.2 Improved traditional canals and water control structures

Many of the water control structures used in modernised spate systems are similar to those used in conventional perennial irrigation practice, but there are some important additional features that have to be considered in spate schemes.

A canal network will already be in place when existing spate schemes are being improved. Improved canal networks, supplying water to controlled field outlets, can give better control and overcome some of the other disadvantages of the field-to-field water distribution system, but will probably also require a change in the way that water is distributed. This could have a large impact on existing water rights. Any improved system must ensure that irrigation can be carried out quickly, in the short periods that spate flows occur. Experience suggests that major modifications to canal systems of farmer-managed schemes should not be considered unless there is significant siltation, scour, or canal breaching problems, or farmers request improvements. Any interventions should obviously be developed with the farmers. This ensures that they understand and agree with the implications of any implied changes to water distribution. If new canals are proposed, farmers have to agree to provide the additional land that will be needed, as this will almost certainly have to be taken from previously irrigated land.

Improved canals

In existing schemes, where canals are performing reasonably satisfactorily, the design of any new or extended canals should be based on the slopes and cross sections of existing traditional canals, derived from surveys. If the discharge capacity is to be changed, then the survey data can be used to select a canal design method that best predicts the existing canal slopes and dimensions. The selected method can then be applied to design the new canals. It is important to note that conventional “regime” canal design methods were developed for canals in perennial irrigation systems that are operated within a fairly narrow range of discharges and have a small sediment input. This contrasts with the situation in spate canals, where discharge varies rapidly over the full range of flows from zero to the maximum discharge. Sediment inputs are very large and canal designers are not free to set the canal cross section and slope to carry the required discharge, without also providing an appropriately high sediment transporting capacity. This rules out the use of most conventional canal design procedures. Canal design methods are discussed further in Annex 4.

New and improved canal structures

Check and Drop Structures

In a traditional spate system the main distribution canal is blocked by a series of earthen embankments (bunds) that divert the water to branch canals[17], or to a group of fields. This is a simple system with clearly defined operation, but bund reconstruction is difficult while there is water in a canal and farmers do not like the recurrent costs of rebuilding the embankments. Farmers will often request better control structures when schemes are being improved.

One option is to provide an intermediate design of combined check/drop structure. This comprises a basic drop structure, combined with an earthen embankment for heading up the flow. This type of structure often features in the more mature traditional systems where there are substantial drops between fields. An important feature is that the earth embankment is not constructed within the structure, where there is a significant risk of seepage failure along the earth - structure interface, but is built upstream. The use of an

[17] In large floods water may be allowed to flow to several branches at the same time.

earth embankment keeps the operation similar to the situation of an embankment without a structure. Provision of gates makes operation simple and eliminates the need to re-construct bunds after each flood. Disputes between upstream and downstream farmers may result as there is now the ability to head up flows at any time, which is not possible in a flowing canal once an embankment has been breached.

A primary function of this type of structure is to limit the scour hole that forms when an embankment is breached. Drops usually have unlined stilling basins and crests that can be progressively raised to reflect the general rise in the overall system.

If more conventional gated combined drop/check structures are adopted for spate schemes then the following issues need to be considered:

- If the traditional water distribution practise is unchanged, then each structure along the canal will, in turn, receive the full canal flow less any losses. All structures have to be designed for the maximum canal discharge.
- Gates are relatively expensive. Stop logs are much cheaper, but are not recommended as they are difficult – usually impossible, to remove during spate flows.
- Is it necessary to ensure that upstream water level is below any off takes when a structure is open to allow flow down the canal?
- Does the structure need to raise the canal bed level?
- What provision needs to be made to pass excess flow in the event that a large flood arrives and the structure is closed? Can excess water safely spill over the upstream banks or does the structure need to include spill capacity?

An upstream view of a conventional combined gated check and drop structure used in a spate scheme is shown in Figure 10.26.

Figure 10.26 Gated combined check/drop structure – Yemen

There will be a requirement to dissipate substantial energy when a structure incorporates a drop in order to permanently raise the upstream bed; or excess flow spills over the structure; or a jet of water flows under a partly open gate. In conventional systems a stilling basin is used to dissipate this energy safely. Conventionally designed stilling basins can add substantially to the cost of structures. This cost can be reduced by (a) accepting turbulence and some scour downstream of the structure and providing a shorter basin; or (b) providing an unlined basin, with side wall foundations deep enough to avoid undermining and accept temporary scour during periods of high flow.

Flow splitting structures

There is often a need to provide flow-splitting structures to reduce the flows in flood canals to smaller more manageable discharges. Division structures are important and may be one of the most justifiable investments when spate schemes are being improved. One approach used in Eritrea is to provide a hardened flow splitting structure that can be constructed from gabions, that splits high flows into two channels and provides a durable hard point that farmers can use to anchor temporary diversion bunds that are adjusted from spate to spate to manage the distribution of lower flows. An example of such a structure constructed in Eritrea is shown in Figure 10.27.

Figure 10.27 Gabion flow bifurcation structure in Eritrea

In some systems it is agreed that the flow at a particular location should be divided into fixed shares, but often there is no structure to ensure the agreed split occurs. Division structures are best designed as two similar structures side by side with crest lengths proportional to the agreed flow split. These could be check structures or off-takes according to conditions. The design needs to take present and future tail water conditions into account since high tail water into one branch will change the balance of flow distribution. In some situations a single weir feeding into two branches may be sufficient. Provision may be made to place stop logs to adjust the balance of flows if this is agreed and it is not anticipated that the stop logs will need to be adjusted when the canals are running.

10.3.3 Field off-takes

While some spate schemes have a recognisable canal system serving each field, field-to-field irrigation is usually practised. Under this system, the upper-most field receives the water first and it is allowed to pond to a pre-determined depth. When that depth is reached the field bund is breached and the ponded water is released to the next field. Meanwhile, any incoming flow passes through the first field to the next one. This process is progressively repeated.

The main advantage of this system is that water is applied quickly at high flow rates, during the short time that spate flows occur. Also there is no investment in, or land lost to, a separate canal system. Crops in upstream fields may be damaged if there is a flood when the downstream land is still entitled to water. Further, the lack of separate channels means that more water will percolate en-route and less reaches the downstream areas, (an advantage for the upstream fields).

The normal upstream-first hierarchy for spate irrigation means that the flow capacity of field off- takes has to be sufficient to take the full incoming canal flow. Properly engineered large capacity off-takes are expensive. Open channel off takes are less expensive than gated culverts. Whether off-takes need gates or other means of closing will depend on the canal water level when any check structures on the canal are open.

In more conventional water distribution systems, where water is supplied to a number of field off- takes at the same time; there is still a requirement to provide large off-take capacities. Very large irrigation duties are required in spate schemes to supply water at the flow rates wanted by the farmers.

10.3.4 In-field structures

Fields naturally form into a series of level terraces. There is therefore a difference in level between each field and the next downstream. This difference increase over time as the upstream fields receives more water and sediment than the lower fields. Water flowing from one field to the next will cause erosion, the extent of which will depend on the drop, the flow and the soil conditions. Drop structures between fields may therefore be needed to control erosion.

An example of a gated field water distribution structure used in a modernised spate system in Yemen is shown in Figure 10.28.

Figure 10.28 Gated field distribution and drop structure, Yemen

11. Spate irrigation and river basin resource management

11.1 LINKAGES

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 with a limited capacity to adjust to rapid change. If the use of natural resources, such as land and water, is changed over a short period 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 also very much part of these natural resource systems and are themselves affected by changes in the land and water resources in the river basins.

This chapter describes main linkages – the effects that river basin management has on spate irrigation and the effects of spate irrigation on river basin management. These are summarised in Table 11.1.

Table 11.1 Linkages

Issue	Spate irrigation impacts	Spate irrigation is affected by
Biodiversity and natural vegetation	Spate systems are depositories of local biodiversity	Wild plants and trees are often additional sources of income. Mesquite infestation had a negative affect on command area utilization
Catchment degradation	Cutting of trees for traditional diversion structures may contribute to the degradation of catchment	Catchment degradation changes run off patterns and increases sediment loads
River morphology	Spate systems tend to stabilize river morphology Encroachment of river beds creates 'vulnerable areas'	Catchment degradation and cutting of reverine forest and bank vegetation causes changes run off regime and may trigger down cutting and widening of wadi beds
Ground water recharge	Spate irrigation concentrates recharge in the irrigated areas. Total recharge is reduced because of evaporation losses in the command area	In fresh groundwater areas conjunctive use of groundwater and spate flows can sustain highly productive agriculture
Dune formation		Prolonged drought can lead to abandonment and to desertification Dune formation particularly threatens the fringes of spate systems
Flood management	Spate systems intercept moderate to medium flows, only peak floods are passed on down the wadi	Floods change river morphology and affect viability of spate systems
Upstream and downstream water use	Spate irrigation will reduce water availability for downstream use	Intensification of upstream water use may change water availability and flood hydrographs without necessarily leading to more productive water use for the river basin as a whole

11.2 SPATE IRRIGATION, 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 riverbed 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, animals and in particular birds. In Balochistan (Pakistan), spate flows have contributed to the development of wetlands, which are excellent refugee for migratory birds (Nawaz 2002).

Natural species of vegetation are often of considerable value. A sample of native species occurring in the spate irrigated area of DG Khan and in Pakistan and their productive uses is given in Table A5.1 in Annex 5. Grasses and shrubs for instance sustain livestock population, while trees are used for various purposes. Tamarisk (*Tamarix L.*) trees are used for fuel, utensils and tanning, while Gum Arabic *(Acacia nilotica (L.) Willd. Ex Delile)* trees are used as timber, fuel wood and the construction of protective fences. Indian jujube *(Ziziphus mauritana Lam.)* is a typical multi-purpose tree providing fodder, fuel wood, timber and fruit, while it is also used for medicinal purposes and bee-keeping. In Pakistan, the dwarf palm used for the production of mats, ropes and sandals. In the spate irrigated areas of Pakistan, the harvesting of various types of mushrooms is a lucrative side 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 to survive these adverse periods.

There is considerable variation between spate systems with respect to the degree of natural vegetation that occurs. There is a large diversity of wild vegetation in the spate systems in Pakistan, Sudan and Ethiopia, while the spate systems in the Tihama in Yemen are largely devoid of natural vegetation. Reportedly, the Tihama used to be covered by trees and was much greener in earlier days. Most of the woodlands were cleared to create agricultural land. Only scattered trees are left, such as Gum Arabic on the fields and Tamarisk and *Salvadora spp* on the riverbanks (Scholte, 1991). Mechanisation of spate-irrigated agriculture, including an increasing use of tractors, has intensified the clearing of land and many of the remaining scattered trees have been destroyed.

At the other end of the spectrum, there are spate irrigation systems where natural vegetation is out of control. In the spate irrigation systems in Gash and Tokar in Sudan there was a severe invasion of Mesquite *(Prosopis juliflora (SW.) DC.)* and Algarrobo *(Prosopis chilensis (Molina) Stuntz)* in the late nineties (FAO, 2000). The problem is to a large degree a 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 produce charcoal from it. Under the new Gash Livelihoods Project the eradication of mesquite is foreseen in combination with land titling. Consideration of mesquite's economic importance as the primary source of cash income, particularly for the landless and its use in river bank stabilisation will be needed. The project will identify suitable alternate non-invasive tree species for establishment on public lands and women's group woodlots in the area. Such tree species will include tree legumes well as other trees with extensive root systems.

11.3 SPATE IRRIGATION AND CATCHMENT DEGRADATION

The construction of brushwood spurs and weirs requires substantial numbers of trees and branches. Because of its interlocking properties acacia branches are preferred. The intensive use of acacia trees, 28,000 trees required annually in the 3,000 ha systems of Sheeb in Eritrea for example, is a serious threat to the long-term sustainability of spate irrigation in the Eastern Lowlands. Farmers estimate that it now takes 10 times longer to gather the acacia shrubs need to maintain their system than in the past. Similarly, in the Border Area of Sudan, Niemeijer (1993) describes how brushwood flood spreading structures were built from branch or doum palm *(Hyphaene thebaica (L.) C. Martius)*. This has now largely disappeared from the area and the steep decline of water spreading is associated with its loss.

Figure 11.1 Collection of shrubs for the repair of flood diversion spurs, Eritrea

Denudation of the areas close to irrigated areas is associated with the construction of diversion bunds and the collection of wood for fuel and construction. There are many other factors that cause deforestation and land degradation in the upper catchment areas where spates flows are mostly generated. These include expanding agriculture and overgrazing driven by rising populations, breakdown of indigenous terracing and other erosion control measures, Scholte *et al* (1991). The phenomenon is not new. Pollen studies near the pre-Indus site of Nauwshero on the Kacchi Plains, Pakistan suggested that in 2600 BCE a dramatic shift in vegetation had already taken place. One theory is that this was caused by the development of spate irrigation and the larger population pressure on local natural resources. Spate floods become flashier and more silt laden due to degrading catchments.

11.4 SPATE IRRIGATION AND RIVER MORPHOLOGY

Spate irrigation occurs either in mountain valleys or on the plains close to the mountain front, at the end of a gravel fan. In these latter areas, wadis tend to be unstable. Spate irrigators attempt to stabilize these sections as the sustainability of spate irrigation depends on the river not changing course dramatically, or bed levels silting up or degrading. Even then spate systems are subject to disturbance when large floods occur. Changes in the river morphology may have their origin in the lack of protection of local vegetation – the cutting of riverine forest or of river bank vegetation, but are also be triggered by historic floods that result in a general lowering of river bed levels.

There is usually a gradual transition in the vegetation along spate rivers. The upper reaches experience more frequent floods, and the physical disturbance that comes with them removes the vegetation. In the lower reaches of ephemeral rivers 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 the river beds also plays an important role in their stabilisation. This is particularly true in spate rivers in alluvial plains, which do not have beds armoured with gravel and cobbles and are prone to scour. While the degradation of the riverbed is often a natural phenomenon, the speed and intensity of degradation can be increased by human action, such as the cutting of trees and bushes in and along the riverbed as well as the degradation of wadi catchments. 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.

Degradation of a riverbed may advance to such an extent that canal intakes are left so far above the wadi bed that diversion becomes impossible and the intake and canal is abandoned. An example is the Yandefero River in Konso, Ethiopia. Here the historic “El nino” floods that occurred in 1998 resulted in a rapid degradation of the riverbeds in the region and erosion of the riverbanks. Cutting of vegetation and free cattle grazing contributed to these effects, which rendered many exiting intakes unserviceable. (Farm Africa 2003)

Figure 11.2 Canal head abandoned due to lowering of the riverbed and erosion of the riverbanks, Yandefero, Ethiopia

While river bed degradation is sometimes linked directly with recent land use changes, wadi beds move up and down in response to the pattern of floods that are experienced and this natural process is not necessarily related to the destruction of vegetation, see Chapter 4. Abandoned intakes and canals that can no longer be commanded 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 due to the degradation of the riverbed (Halcrow 1993). The recent history of the Korakan River in Balochistan, Pakistan illustrates the impact of the degradation of the riverbed on the livelihoods of many households. Until the early 1970s, about 2,000 households living in 30 to 40 communities depend upon 11 collective diversion bunds and a large number of individual structures for the irrigation of their fields on both river banks. Due to the cutting of trees and overgrazing of vegetation in and along the riverbed, the degradation process started in the downstream reach of the river at the beginning of the 1970s. Between 1976 and 1989, seven of the eleven bunds could not be rebuilt by the farmers as the level of the riverbed had become too low and the river became too wide. As a result, many fields have not been irrigated for many years and their owners have migrated to other areas in search of employment, (Halcrow 1994).

Figure 11.3 Riverine forest and natural vegetation, Yandefero system in Konso, Ethiopia

Vegetation also sometimes helps in raising the river beds. When trees, such as Tamarisk, colonise the bed of spate rivers, flows are slowed down, sediment settles and bed levels rise. In many rivers prone to degradation, for example the Wadi Tuban in Yemen and the Korakan River in Balochistan, the spate irrigation farmers have put a ban on cutting vegetation along the wadi bed in place.

The use of vegetation for flood protection has the important advantage that it not only withstands normal floods, but regeneration is possible by re growth, when damage occurs during exceptional floods. Vegetation reduces the speed of flow, allowing sediment to 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. However, the distribution of natural vegetation in spate rivers is limited to sites of low speed flow, where seeds are deposited and covered with enough sediment to obtain germination. In sites characterised by swift currents, vegetation establishment can only be obtained by planting cuttings deep and offering protection against scouring. Rouchiche, quoted in Camacho (2000) has proposed outline designs for protecting the outer curves of spate streams, see figures 10.20 to 10.22 in Chapter 10.

11.5 SPATE IRRIGATION AND WIND EROSION

In many spate irrigation systems, the risk of sand dune formation is ever present. El-Hassan (1999) gives an overview of the change in land use in the Tihama plains in Yemen. A study by FAO using aerial photography dating from 1976 and 1987 for Wadi Zabid suggests that 5 percent of the productive area was lost to sand movement in this period. Another study using satellite imagery for 1973 and 1990 suggests that it is mainly rainfed farming land, not spate irrigated land that is converted to sand dunes. This is related to the fragile nature of rain-fed farming (El-Hassan 1999). There are several explanations for the increase in the area occupied by sand dunes. One is that agricultural land has stretched increasingly into marginal areas. The heavy pumping and falling water tables – particularly in this part of the Tihama – and the reduced probability of spate supplies after the modernization of the systems is said to have caused the degradation at the fringe of the formally spate irrigated areas. A third explanation offered by Scholte *et al* (1991) is the practice of rain-fed agriculture in the sand dune areas. In the exceptional years when there is adequate rainfall for rain-fed agriculture, natural vegetation is uprooted mechanically or by hand and millet is planted, and animals graze the area after the harvesting of the millet. As a result, the sand dunes are stripped of natural vegetation, and regeneration is slow and difficult.

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

A closely related problem is wind erosion. The deposition of coarse sediments in the command area has a negative affect on soil water retention capacity (see also Chapter 5). Wind erosion also tends to remove the finer soils. The continued use of the spate systems is to best strategy to minimise these impacts.

11.6 SPATE IRRIGATION AND FLOOD MANAGEMENT

In Pakistan the development of spate irrigation systems has been advocated on the grounds that it would help reduce damage to the large perennial canals on the western extreme of the Indus irrigation system. The hill torrents rising in the Suleiman Hills, and to a lesser extent the Kirther Range, have at times caused considerable damage to the large-scale perennial irrigation systems. Damage to the Flood Protection Bund in Sindh from flash floods from the hill torrents in 1995 was estimated at US$6million. 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 infrastructure on the perimeter. For example Chasma Right Bank Canal, the Dera Ghazi Khan Canal, the Flood Protection Bund Complex and the Pat Feeder Canal (NESPAK 1998).

There is a limit however to the contribution that spate irrigation development can make to flood mitigation. Very large floods – that cause most flood damage – are not retained in spate irrigation systems as spate irrigation makes use of low and medium floods. Widespread development of spate irrigation in the catchments and tributaries or the larger wadi systems can reduce the chance of large floods building up. Spate irrigation systems also tend to stabilize ephemeral streams, which avoids unexpected downstream breaches.

In general there is little experience in managing spate irrigation systems for flood retention, either for flood mitigation or for artificial recharge. Most experimental work on flood water retention has been done in Iran by the Soil Conservation and Watershed Management Research Institute. Starting from a pilot project at the Gareh Baygon Plain a number of measures under the name 'abkhandary' were implemented on 60,000 ha of land. The main purpose has been the spreading of flood water for recharge on alluvial fans, reviving the vertical well systems (qanats) and encouraging the development of new wells. In several of the flood spreading sites part of the water was also used for spate irrigation.

In a typical flood spreading project water is diverted from the bed of an ephemeral river and channelled through a desilting basin and a supply and spreading channel. It is then spread over a number of bunded fields. The bunds run along the contours and channels collect the excess water and pass this 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 – in particular (Nejabat no date; SCWMRI 2003):

- Effective recharge of for instance 78 percent in the Narma Shir Bam project (Kerman Province)
- The damage produced by a large flood in Gareh Baygon was estimated to cost only 2.5 percent of the cost that would have been incurred on the properties, had the flood flows not been captured by the flood spreading system (Rahbar and Kowsar, no date)

The main purpose of the flood water spreading carried out to date has been to enhance groundwater recharge – not spate irrigation. Where spate irrigation occurred, it was a side activity. Following the positive results in Iran, similar flood water spreading activities were envisaged in Lorelai District in neighbouring Balochistan. These had to be shelved, however, as all spate flows and run-off was already claimed under existing customary rights.

11.7 SPATE IRRIGATION AND GROUNDWATER RECHARGE

The cropping patterns in Wadi Tuban and Wadi Zabid in Yemen have changed dramatically, mainly due to the remarkable increase of shallow wells since the 1980s. As a result, the area under banana has increased from 20 ha in 1980 to more than 3,500 ha in 2000 in Wadi Zabid, while about 2,300 ha are under vegetables in Wadi Tuban. The link between spate irrigation and groundwater recharge is particularly important in Yemen. Many spate irrigation areas have been transformed into areas of high value agriculture, with bananas and mangoes as main crops, dependent on the conjunctive use of spate flows and groundwater. Groundwater quality in coastal Yemen and parts of Hadramaut is generally good enough for irrigation, unlike that in spate areas in Pakistan, Tunisia and Eritrea. In Sheeb in Eritrea for instance groundwater salinity ranged from 1,200-1,800 μs/cm and in Wadi Labka from 2,250-2,650 μs/cm. In areas with high salinity irrigation from groundwater is not an option. However small prisms of fresh water stored in the bed of the spate rivers can be important source of drinking water supply in areas with generally saline groundwater.

Two types of aquifers are important in spate irrigated area. In valley bottoms one finds strip aquifers. The alluvial sediment deposits consist of generally unsorted, but coarse and poorly cemented material with high permeability. The deposits are found in a strip along the riverbed that may vary in width from a few meters to a few hundred metres. Strip aquifers have very favourable recharge conditions and are recharged from infiltration of spate flows and from springs and seepage zones along the wadi bed. Because of their small volume and high permeability the strip aquifer are quickly depleted.

Another type of aquifer is found in the lowland systems at the alluvial fans and on the plains. They are actively recharged by the wadis and may be several thousand feet thick. They may not be homogeneous and instead 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 recent years in Yemen these coastal aquifers have been intensively developed.

Since the modernization of the Wadi Zabid system in Yemen the area under cultivation has increased substantially. This seems to be strongly 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 conjunctively with surface supplies, as well as a single source of irrigation water. Since the 1970s there was a rapid increase in well development, mainly shallow wells with some extension. In 1988 1,411 wells are recorded in Wadi Zabid, 1,221 of which are pumped. These were almost all used for irrigation – but served as an important source of drinking water at the same time. Most well development had been along the axis of the Wadi and most wells are located in the lower Wadi areas near the coast, where depth to groundwater is less. Saline water intrusion was already a fact in Zabid, and a recent water resource study observed that it would be hard to reverse.

The intense use of groundwater and the higher 'water productivity' of groundwater based irrigation raises questions on the relation between spate irrigation and groundwater recharge. The issue is whether the best spate water management strategy would maximize recharge, or agricultural productivity of the spate irrigated areas. The relationship between spate diversion and recharge is not well quantified, although some information is available from water balance studies carried out in spate irrigated areas in the Yemen, see Chapter 4.

It is thought that most recharge occurs through infiltration in the wadi beds. This may be enhanced by spate irrigation, where diversions flatten the river slopes, and in the case of diversion bunds, produce ponding, and reduced flow velocities. However most of the water diverted onto the land is accounted for by evapotranspiration, and the proportion of recharge is less.

11.8 SPATE IRRIGATION AND WATER STORAGE

The reliability of spate irrigation would be greatly increased if water from flood peaks could be stored and then released when needed for irrigation. Construction of small dams is a fashionable activity on many semi arid regions at present. However the benefits in terms of irrigation and recharge to local upstream communities, where there are any, need to be balanced by the adverse impacts on downstream spate irrigators. Hydrological studies on Wadi Zabid and Wadi Tuban in Yemen suggest that in the last ten years the inflow to the spate irrigation areas may have reduced by about 30 percent. The reduction is attributed to the development of a large number of small dams in the upper catchments, (IIP 2002). These upstream developments change the run off pattern, with low flows and the earlier parts of the flood wave being intercepted by the dams, while downstream systems receive the flood water that cannot be retained and are spilled. 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 small to medium discharge ranges.

Dams are not an option in many spate-irrigated areas due the rapid siltation rates that occur when dams are supplied from spate rivers carrying very high sediment loads. Very expensive dams with a very large initial capacity (and therefore expensive) are needed in order to provide enough storage for sediment deposits to achieve a reasonable economic life. Use of dams in the spate irrigated areas of Eritrea, where sediment loads can be as high as 10 percent by volume, has been ruled out as an option fro this reason. Another example of controversial upstream development is the Gomal Zam Dam in DI Khan in Pakistan, which will come at the detriment of spate irrigated agriculture in a substantial area, and the longevity of the dam – due to heavy sedimentation – has been seriously questioned in a series of feasibility studies. The issue is that in many semi-arid areas there is pressure from politicians and funding agencies to respond to the water crisis by building dams, even in situations where there are more viable alternatives, such as improving spate irrigation[18].

It can be argued that storage of water in the soil profile in spate irrigated areas is a cheaper option than building dams, see Box 11.1.

Box 11.1 Comparative costs of storing water in shallow aquifers and dams

Kowsar (1995) makes a strong case for storing water in shallow aquifers rather than in dams in semi-arid areas. He argues that the entire storage capacity in reservoirs in Iran amounts to 30 km^3 and that the cost of developing this capacity is US$0.20 per m^3. The total potential storage capacity in debris cones, alluvial fans and colluvial soils in Iran is 4,300 km^3 – equivalent to ten times the natural precipitation in the country. The identification of possible sites for recharge hence should not pose a problem. The cost for creating 1 m^3 of storage capacity under artificial recharge – using the model experimented in Gareh Bygone in Iran – is USD 0.0008. The cost of water actually stored, based on average precipitation and a conservative figure of 30 percent effective recharge would be US$0.027 per m^3. However the costs of utilizing this water, (pumping), will reduce this cost advantage to some extent.

In case of spate irrigation the cost of storage in the soil profile may be calculated. Assuming that 600 mm of water is stored, an investment of US$1,200/ha in a new spate irrigation system would be more cost effective than a comparable investment in a storage reservoir, taking the Iran figures as the norm. This includes all the low cost investments approaches described in this study. Obviously non-comparable quantities are compared – but investment in floodwater spreading or spate irrigation seems to have

[18] This comment also applies to dam construction in semi arid areas where the rivers carry very high sediment loads. Many effective and sustainable dam projects, particularly communal small dam projects, provide great benefits to poor rural communities.

has advantages over investments in dams in semi-arid areas, where dams suffer from rapid sedimentation and high evaporation, substantially reducing their positive benefit.

A comparison of water resource development through spate irrigation and perennial dam based irrigation is given in Table 11.2

Table 11.2 Comparison of spate irrigation with perennial dam-based irrigation in arid areas

Spate irrigation	Perennial irrigation (dam based)
Insecure supplies, unless combined with groundwater irrigation,	Secure supplies, provided dam has reasonable catchment, and a reasonable useful life before it fills with sediments
Water storage in soil profile – very low evaporative losses	Water storage in reservoirs, high evaporative losses in shallow dams
Investment cost per m^3 water stored low	Investment cost per m^3 water stored high
Sedimentation contributes to soil fertility	Sedimentation causes reservoir siltation
Cannot utilize peak flows	Can store peak flows

12. Recommendations for improving spate irrigation

Recommendations for improving or developing spate irrigation systems are presented in this chapter, in two parts. The first part presents general recommendations that apply to most schemes and are mostly concern development approaches and policy issues. The second lists more particular recommendations for engineering and management interventions. Topic related recommendations derived from chapters 3 to 11 are given in the third part.

IFAD[19] published an evaluation of their experience of large spate irrigation systems modernised with gated, permanent, diversion structures and new canals in Yemen in the 1980s. They found that future interventions in spate irrigation should favour low-cost diversion structures and avoid sophisticated technical solutions, which had proved to be economically unjustifiable and difficult to operate properly. IFAD 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) 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 last few years to the modernisation and rehabilitation of large spate systems, carried out with support from International Funding Agencies. Initiatives in smaller systems, where farmers control the selection of options, have generally been more successful.

12.1 GENERAL RECOMMENDATIONS

Development approach
The selection of an appropriate development concept for spate irrigation systems of any scale requires a clear understanding and appreciation 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 may be changed (if at all) by the improvement project.
- The socio-economic circumstances and risk avoidance strategies of the spate irrigating farmers. Projects should be planned with adequate time and resources to fully understand farmers' perceptions and strategies. A long-term programme is required, as adequate time needs to be allowed for stakeholders to adapt to changed technologies. Note: This recommendation may conflict with the time bound programmes of typical internationally funded development 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. In this regard it is important to explore the possibilities of engineering approaches that are in line with these capabilities.
- The scope for improving the efficiency of water diversion and distribution in traditional systems that often already utilises a large proportion of the spate flows available for diversion. Improvements in water distribution and moisture

[19] http://www.ifad.org/evaluation/public_html/eksyst/doc/lle/pn/l100irre.htm

conservation in the soil profile may be more beneficial, than focussing solely on improving the efficiency of diversion.

- Water use efficiency at the river basin level, because water perceived as being lost to a particular spate system may in fact be used downstream, may recharge groundwater or be used for useful, non-agricultural purposes such as riverine forest or rangeland.

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 will largely depend upon the following principles:

- 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.
- Continuous management is preferred over a one-time project-type improvement. Under such active management farmers with the help of local government or NGOs, quickly adjust to changes, such as embankment breaches and scouring or silting of flood channels.
- 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.
- The replacement of several independent traditional diversion structures by a single permanent "engineered" diversion structure eliminates the need for farmers to rebuild diversions after floods and increases control over flood flows. However concentrating diversion by means of a permanent structure at one location can result in conflict between upstream and downstream farmers due to the inequitable distribution of available 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) that appropriate sustainable levels of maintenance can be assured for technically advanced diversion structures.
- Spate irrigation recharges ground water and the use of shallow ground water for irrigation is increasing in many spate-irrigated areas. Adoption of an integrated water management approach involving both spate irrigation and irrigation from shallow ground is recommended in wadi systems where there is sufficient shallow groundwater of suitable quality to make supplementary pump irrigation a feasible option.

Simultaneously with engineering improvements agricultural improvements should address:

- Improving the yields of traditional and new drought resistant spate-irrigated crops, in particular fodder crops.
- Improving the productivity of livestock production, which usually provides an important part of spate irrigator's livelihoods.
- Improving access to credit, agricultural inputs and markets for cash crops.

12.2 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.

12.2.1 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 organised on a district or regional basis through local government, or through the use of 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 scour and overturning and should also 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.

12.2.2 New schemes in areas where spate irrigation is being introduced

Former rain fed farmers 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. (A typical simple diversion of this type was described in Chapter 10.)

12.2.3 Medium/large scale schemes under farmer management using traditional diversion practices

These schemes are constructed in larger wadis carrying much larger flood flows. Typically they will have numerous intakes ranging from simple deflectors at the upstream end of a wadi and diversion bunds in the lower reaches. One option is to continue to treat these schemes as a series of independent small systems and to apply the options already described under 12.2.1 above. In some cases it may be prudent to work on the tail-end systems only. 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 and a higher level of engineering is needed to ensure that diversions are robust enough to provide the lifetimes expected by farmers. (Shorter lives may be acceptable to farmers than would be provided by conventionally engineered structures in water projects.)

A second option if affordable, is to provide more permanent gated diversion structures, while minimising the extent to which previously independent canals are consolidated to reduce the number of diversion required. Cost considerations will probably dictate application of a value-engineering approach including the use of fuse plugs to reduce the cost of diversion weirs. As already mentioned 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) sustainable levels of maintenance can be assured.

12.2.4 Large schemes with improved infrastructure and agency management

Larger and technically complex systems are only feasible with an element of external management ranging from full agency management, to backstopping and technical support provided by local irrigation or agriculture departments. 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 because of the difficulties of ensuring that a greatly improved ability to manage spate flows is not misused to the disadvantage of downstream water users. There is also be the requirement to ensure the funding of adequate levels of maintenance in agency managed schemes and avoid inheriting potential technical problems with “engineered” spate diversion structures.

12.2.5 Schemes with access to sufficient shallow groundwater

Conjunctive use of 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. However provision of credit to allow farmers to purchase wells and pumps should be regulated to prevent rapid over exploitation of shallow groundwater and in coastal areas saline intrusion and the destruction of aquifers. Provision of communal wells to enable poorer farmers to benefit from groundwater irrigation could be considered. Properly conducted regional water balance studies are needed before shallow well irrigation is actively promoted in spate areas.

12.3 TOPIC BASED RECOMMENDATIONS

12.3.1 Improving the livelihoods of spate irrigators (Chapter 3)

An understanding of the socio-economic circumstances of farmers and the coping strategies that they adopt to cope with is essential if effective and sustainable improvements to traditional spate irrigation systems are to be developed. This knowledge can help planners and designers to avoid the unintended negative consequences that result from some past spate irrigation improvement projects.

To alleviate poverty in spate-irrigated areas it is not sufficient to focus only on the improvement of spate irrigation. Water is not the only constraint to improving the productivity of spate-irrigated agriculture and many poor households rely only partially on spate-irrigated agriculture for their incomes. Successful alleviation of poverty among poor households in spate-irrigated areas also depends upon:

- Improvement of access to inputs extension services, credit and marketing for spate-irrigated crops.
- Improvement of the productivity of livestock as well as the processing and marketing of livestock products.
- Creation of opportunities for wage labour and off-farm income, in particular for landless households.
- Development of conjunctive use of ground water and spates, including access to credit for installation of communal wells with pumps, where possible.

Spate irrigation projects with the objective of poverty alleviation should develop and implement activities in these areas, so that poor households in spate-irrigated areas have the chance to substantially increase their incomes. While not all projects will have components covering the range of livelihood issues, they 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.

12.3.2 Determining the available water resource and "design floods" (Chapter 4 and Annex 2)

In most schemes the long-term data needed to design diversion structures and canals will rarely if ever be available. In particular due to the seasonal and inter annual variability of spate flows it is very difficult too directly determine the volumes of water that will be diverted and hence the potential cropped areas.[20] For small and medium scale schemes simple methods are appropriate that require minimal data on the magnitudes and patterns of floods.

If estimates are needed when existing schemes are being improved the most reliable procedure is to base assessments on existing cropped areas. This involves surveys and analysis of aerial photographs, when available, to determine the extent of the existing irrigated areas. Surveys have to combine with local knowledge and supplemented by interviews with farmers to establish how often fields in different parts of the system are irrigated and how this varies from year to year.

- For new schemes with a single diversion point approximate estimates of the proportions of annual flows diverted to a canal can be derived from non-dimensional flow duration curves. (Examples of the application of simple procedures suitable for use in small projects when minimal data are available are given in Annex 2.)
- It will also be necessary to make an estimate the likely variations between years. When data are not available this can be achieved by assuming that the annual run off volumes are approximately proportional to the numbers of floods that occur and using farmers' estimates of flood numbers.
- The magnitude of flood discharges with different return periods is needed to design diversion structures. In many cases application of regional flood frequency relationships together with water level and discharge estimates derived for historic floods provide the most reliable results.

[20] In large projects stochastic hydrological modelling can be used to derive this information, but the resources and expertise required will rule out this approach in most cases.

12.3.3 Managing sedimentation (chapters 4 and 10 and Annex 4)

Wadis can transport mostly fine sediments at concentrations rising to and exceeding 10 percent by weight in floods. The ability to cope with high sedimentation rates in the command areas and canals is thus critical to the success of spate irrigation. While traditional intakes and canals can generally cope with sedimentation, new "permanent" intakes and canals have to be designed to cope with field levels that may be rising by up to 50 mm/year. When new permanent or semi permanent diversions are proposed the following measures are recommended:

- Estimates of the rise in command levels expected over the engineering life of structures should be developed and used to estimate the change in command over the design life of the structures, (see Annex 2).
- Weirs, intakes and water control structures should be designed to provide command over the engineering life of the infrastructure.
- Weirs should be designed either to provide water levels at final command levels or to be raised during the life of projects.
- Intakes should be provided with breast walls formed from removable panels that can be taken out to compensate for rising command levels. It may also be necessary to provide a drop structure at the head of the canal that will slowly silt up over the life of the project.
- Intakes should be provided with effective sediment sluices that are designed to be operated during the very short periods when flood flows exceed the flows diverted to a canal. Small settling basins designed to trap coarse sand, gravel and larger sediments, before they can enter, settle and block canals are also advantageous. In this case robust and sustainable arrangements for removing sediment immediately following floods need to be provided.
- New canals should have a high sediment transporting capacity, similar to the steep slopes and wide shallow cross sections that are observed in traditional canals, (see Annex 4).

12.3.4 Soil and water management (Chapter 5)

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 maximise soil moisture conservation may have as large or larger impact on crop production than improving water supply. It should be considered as a component of spate improvement projects in schemes where soil moisture conservation is not currently practiced.

Several techniques to conserve soil moisture can be applied spate systems:

- Ploughing prior to irrigation
- Ploughing after irrigation
- Conservation tillage
- Breaking soil crusts.

It is recommended that soil moisture conservation techniques be promoted in spate irrigation improvement projects where they are not currently practised. Field experiments in co-operation with farmers are a means of identifying and promoting the most appropriate measures in specific schemes.

A rudimentary canal network with field-to-field irrigation will be in place 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 have negative impacts on water rights. Any improved water distribution system should:

- 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 structures that stabilise the bed of the flood channels, reinforce field-to-field overflow structures and by making sure that gullies are quickly plugged.
- Ensure that water is spread over the command area and does not irretrievably disappear in the lowest parts of the command area.
- 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 that will be needed to construct the canals. Additional land that will be needed to construct canals will almost certainly be taken from previously irrigated land.
- Ensure that interventions should developed with the farmers, as they are generally the ones most able to identify the opportunities and possibilities for improvement in the water distribution.

12.3.5 Agronomy and extension (Chapter 6)

Generally, 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, is relevant:

- Land preparation before flooding
- Moisture conservation through mulching or deep tillage
- Improved field levelling
- Propagation of seedlings
- Times of sowing;
- Crop spacing and plant density
- Staggered planting
- Crop rotations
- Fertiliser applications and weed and pest control
- Improved animal nutrition (and hence draft power and the value of draft animals)
- Farm mechanisation or improved access to draught animals
- Grain storage.

Of these possibly the most important would be development or dissemination of (a) higher yielding but drought pest and disease resistant varieties of existing and new spate irrigated crops; and (b) improved water management and soil moisture conservation practices, as discussed in the previous section.

Other practical measures that need to be considered include:

- Work on the productivity and promotion of some typical spate irrigation crops. One prominent example is clusterbean (guar), the gum of which produces a no-calorie value binding agent and which has a larger potential than so far developed.
- Study and documentation of indigenous pest and disease management practices
- Integration of indigenous technical knowledge with scientific knowledge to increase productivity and system sustainability
- Improvement of existing mixed/inter-cropping systems
- Introduction of vegetable crops in spate irrigation – using pre-irrigation of seedlings
- Establishment of seed banks.

12.3.6 Water rights (Chapter 7)

Water rights and distribution rules in spate irrigation regulate farmers access to water and hence minimise conflict. They make it easier to predict which land will be irrigated, enabling timely land preparation, define the likelihood of irrigation for different areas and hence serve as the key to the collective maintenance and rebuilding of diversion infrastructure. In traditional systems floodwater users depend on one another for maintaining flood canals and reconstructing diversion structures. Agreements on how water is distributed are a precondition for co-operation. Water rights in spate system are not static. They change under the influence of factors such as population increase, pressure for new land development, changing cropping patterns and new marketing opportunities. The introduction of more robust diversion structures, shifts in power relations and changing levels of enforcement can also impact such water rights.

Water distribution rules may not be formally codified or registered, even in relatively large systems. In other systems the water rights developed over a long time period have been formally codified, although not always strictly enforced. The link between (in some areas) declining levels of enforcement and overall governance is very strong. In supporting spate irrigation systems it is important to ensure that there are robust arrangements for enforcing water rights, preferably through local organisations supported by codification and local government facilitation, where required.

It is impossible to plan the development of an existing spate irrigation system without a clear understanding of the rules and agreements that regulate the distribution of spate flows. The following recommendations are made:

- For existing systems water rights and actual practices should be investigated, agreed and where possible codified for use by designers.
- Interpretation of rules is best done by farmers, although there may be some benefit in facilitating discussions to help clarify the actual arrangements in place and the actions taken to respond to changes in water availability or the physical system.
- Arrangements for enforcement need to be considered. The approach followed by the Rod Kohi departments in Pakistan (Chapter 8) provides one model, where the policy is to follow local decisions in disputes. Local elders and community members are expected to reach consensus on sensitive issues. The administration facilitates the process and intervenes only when necessary. Clearly arrangements for enforcement will vary depending on the exiting local arrangements, the strength local government institutions and their interest in spate irrigation.
- For new schemes a basic set of water distribution rules need to be agreed with farmers when the schemes are designed and arrangement for policing and

enforcement agreed. It is desirable that any water distribution arrangements have a high level of flexibility to adjust to unforeseen circumstances. Robust arrangements for agreements are more important than detailed specifications on how water is distributed.

12.3.7 Institutional arrangements for maintenance (Chapter 8)

The viability of spate systems is mostly determined by the strength of the organisations involved in their construction and maintenance. Large, integrated systems can require relatively elaborate organisations, whereas small run-off-the-river diversions 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 specialised 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 externally formalise the agreements for maintenance, these have to be left to farmers, however an improvement project 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 a prolonged periods of crop failure.
- Overhead and transaction costs are kept low.
- Fixed tenure for official posts and positions are avoided.
- In large schemes sub-groups should be strengthened so they can quickly mobilize contributions to maintenance and enforce rules on water management at a local level.
- Extending the role of local organisations 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 can no longer be guaranteed. Strengthening roles of both farmers and local government and reducing the role of specialist agencies will be appropriate in some cases. 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 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.
- Farmer representatives elected from a wide constituency should play an important role in the management of agency schemes. Marginalisation 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 the most appropriate method of management.

In new schemes arrangements for maintenance should be combined with the arrangements for water distribution discussed in the previous section.

12.3.8 Economics of spate irrigation development (Chapter 9)

The scope for deriving significant additional economic benefits from investments in spate irrigation is limited. Apart from costs, a low-cost development approach often has significant sustainability and " ownership" advantages.

The following recommendations are made:

- Economic analysis of development options should include investigation of links between initial costs and subsequent maintenance costs, using realistic valuations of farmers' labour.
- In assessing the benefits of spate irrigation it is useful to use are range of different planning horizons in line with farmers concepts of reliability and appreciation of the dynamic nature of the spate systems, rather than the 20-30 year period that is common in water infrastructure projects. There are several examples where farmers worked on shorter time-horizons, anticipating the changes triggered by one improvement in terms of siltation or scouring of the riverbeds.
- Investments in spate irrigation often have significant social and environmental benefits. These should be included in an economic analysis. As it is not always easy to quantify social and environmental benefits, they should as a minimum be given scores in accordance with their importance and the probability that the benefits would be achieved.
- Project assessments should use these rankings in selecting the preferred options. In addition, it maybe useful to explore different ways of valuing capital in investments that have an explicit poverty alleviation objective
- In assessing the benefits of spate irrigation it has to be recognised that farmers and livestock keepers in these areas often have no viable alternative means of support. The impact of sustaining and support to these natural resource systems differs from investments where the main target group has access to alternative livelihood opportunities.

12.3.9 Water diversion and control structures in spate irrigation systems, (Chapter 10 and Annex 4)

Summary recommendations on engineering approaches were made in the previous section. More technical recommendations are made in Annex 4.

12.3.10 Spate irrigation and river basin resource management, (Chapter 11)

Ecosystems in arid and semi-arid river basins are generally precarious. Due 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 also very much part of these natural resource systems and are themselves affected by changes in the land and water resources in the river basins.

- Spate schemes should be considered in the context of the chain of water uses in the basin and not as an isolated development.
- Spate irrigation may be a cost effective alternative to the development of perennial irrigation supplied from dams in arid areas where the rivers carry very high sediment loads.
- Development options that reduce the unsustainable use of local trees and shrubs used to construct diversion structures should be promoted.
- Use of natural vegetation, specifically planted for river training, provides an environmentally acceptable and lower costs option than the use of conventional “hard” engineering structures.

Studies of the basin wide impact of spate schemes should include:

- Spate irrigation, natural vegetation and biodiversity
- Spate irrigation and catchment degradation
- Spate irrigation and river morphology
- Spate irrigation and wind erosion
- Spate irrigation and flood management
- Spate irrigation and groundwater recharge
- Spate irrigation and water storage in dams.

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Figure A 4.1	Community spate irrigation project

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Annexes

Annex 1 Contract Page

Contract

This report is an output of the Department for International Development's (DFID) Knowledge and Research contract R8065 Improving Community Spate Irrigation carried out by HR Wallingford Ltd. The HR Wallingford job numbers were MDS0540, MDS0545 and MDS 0547. The views expressed are not necessarily those of DFID. The DFID KAR project details are:

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Project title	Improving Community Spate Irrigation
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PL	**Prepared**	
TEB	**Approved**	T Bolle
JCS	**Authorised**	p.p. T Bolle

Annex 2 Hydrology

A2.1 Introduction

This Annex outlines some relatively simple methods that can used to derive the hydrological information needed to design intakes and canals for spate irrigation systems. The emphasis is on methods used for small schemes, where little data is available and the specialist hydrological studies that are carried out in support of larger projects are not feasible. The results derived from these should be verified wherever possible by comparison with any local or regional data that may be available.

For a specific scheme the following information would ideally be available to designers:

a. The seasonal incidence and reliability of spate events.

b. The probability distribution of spate run-off events in terms of peak flows and flood volumes.

c. The distribution of flows during run-off events, particularly the shape of the recession limb of the hydrograph, which provides the bulk of the water that can be diverted to irrigation command areas.

d. The proportion of the annual hydrograph that occurs as low spring fed seasonal base flows and that that can be easily diverted.

e. Wadi bed seepage rates.

f. The magnitude and return periods of extreme peak discharges for the design and protection of the permanent works.

g. The concentrations and size range of the sediments transported by spate events and their relationship with wadi discharges.

In small schemes the long term data needed to provide this information will rarely if ever be available. Simple methods requiring minimal data are appropriate and the maximum use has to be made of the qualitative information on the magnitudes and patterns of floods that resides with the local farmers.

A2.2 Estimating Mean Annual Run-off and potential irrigated area

The proportion of the Mean Annual Run-off (MAR) that can be diverted to the fields is an important parameter in determining the potential command area, although in spate schemes the areas that are irrigated can vary widely from year to year. MAR is conventionally expressed as a run-off depth from the catchment, in mm, but can easily be converted to a volume (m^3) by multiplying by the catchment area in km^2 by 1,000. The proportion of the run-off volume that can be diverted for irrigation depends on the diversion arrangements and the patterns of spate flows that are experienced. This is difficult to estimate without extensive long term site-specific flow data.

In spate schemes the cropped areas are determined in part by the level of risk that farmers are prepared to accept before constructing and maintaining canals and field bunds and preparing their fields. While the fields near the head of a scheme may receive multiple irritations, those near the tail may only receive water occasionally. In some spate schemes in Yemen irrigation is reported to be possible as infrequently as once in five years at the downstream end of the irrigated areas. Farmers also adopt differing irrigation strategies, a few attempting to maximise yields by applying multiple irrigations to small areas, while others more commonly spread the water as widely as possible and often grow a crop from a single large water application. Both strategies may be followed at different locations within the same scheme. The relationship between the flows in a wadi in particular seasons and the areas that are irrigated can thus be quite complex and require a large investment in field investigations and farmer interviews if it is to be fully understood.

The operation and management of most systems is carried out entirely by farmers. Outside agencies rarely become involved in decisions concerning patterns of water distribution and the areas that have priority for irrigation. The calculations described in this section would not normally be needed in these circumstances, as farmers will determine the area to be irrigated based on their past experience and from observation of the quantities of water diverted by any improved diversion and conveyance arrangements. However when new areas are being developed irrigation engineers and agronomists need to determine the potential area that can be irrigated and the capacities of the canals that will be needed. Estimates of the mean annual run-off and the proportion of the run-off that will be diverted, needs to be determined in order to carry out these calculations. Similar calculations are carried out when large existing systems systems are to be modernised.

A2.2.1 Using farmers' knowledge

If estimates of cropped areas are needed when existing schemes are being improved the most reliable procedure is to base assessments on existing cropped areas. This will involve surveys and when available, analysis of aerial photographs, to determine the extent of the existing irrigated areas. Surveys are supplemented with interviews with farmers to establish how often fields in different parts of the system are irrigated and how this varies between years.

Farmers can also provide information on the number and sizes of floods and their variations between years. If surveys of the main canal(s) have been carried out, then slope area calculations described later can be used to convert farmers' estimates of water levels and the periods that canals flow, to make an approximate estimate of the volumes of water diverted from flood events.

Estimates of the impact of improved diversion arrangements can then be based on the additional volumes of water that might be supplied to the fields with improved diversion and conveyance arrangements.[21]

A2.2.2 Estimating Mean Annual Run-off

Using a run-off coefficient

The simplest method of estimating mean annual run-off is to apply a run-off coefficient to the mean annual rainfall over the catchment.

$$MAR = K \times MAP \qquad (A2.1)$$

[21] As many traditional spate irrigation systems are already operating with a high water-diversion efficiency there may not be much scope to increase irrigated areas. The main benefits from spate improvement projects usually stems from a reduction in large labour requirements needed to operate and maintain the traditional intakes and canals.

where
MAR = Mean annual run-off (mm)
MAP = Mean annual precipitation (mm)
K = Run-off coefficient

Run-off coefficients for catchments of wadis might range between 0.05 for larger catchments and 0.10 for smaller catchments. However run-off coefficients can vary considerably, even between adjacent catchments and if this approach is used then a hydrologist with knowledge of the local catchments should select an appropriate run-off coefficient. More sophisticated methods for estimating mean annual run-off are available, but these need to be applied by experienced hydrologists, preferably with a good knowledge of local conditions.

A2.2.3 Calculation of run-off volumes

The annual volume of run-off from a catchment is calculated as the product of the MAR and the catchment area. Catchment areas should be measured 1: 50,000 maps, after marking the intake location(s) and the catchment boundaries, by using a digitiser, planimeter or squared overlay sheet.

Annual Run-off Volume (ARV) = MAR x CA x 1000 (A2.2)

where
ARV = Annual run-off volume (m^3)
MAR = Mean annual run-off (mm)
CA = Catchment Area (km^2)

A2.2.4 Estimating the proportion of annual run-off that is diverted

As mentioned earlier the proportion of the MAR that is diverted depends on the diversion arrangements and the pattern of flows that occur and is very difficult to estimate without long term flow data collected at or near to the diversion site. Very few measurements have been carried out in spate schemes, but information from traditional systems in Yemen suggests that high diversion efficiencies were achieved when numerous intakes are used. Although large floods destroy upstream deflectors water could usually be diverted downstream where the flood peaks had reduced– only rarely did exceptionally large floods pass the last diversion structure.

For new schemes with a single diversion point approximate estimates of the proportions of flows diverted for a range of intake capacities can be derived from non-dimensional flow duration curves, if these are available or can be can be developed from regional hydrological data. An example for two spate rivers in Eritrea are shown in Figure 2.1. In this form of the duration curve the number of hours a wadi flows in different discharges ranges is plotted against the wadi discharge representing the discharge range. The curves are non dimensionalised by dividing discharges by the mean annual flood discharge (Q) and the times by dividing by the total time that a wadi flows in the year, (T). In the absence of more specific local information non dimensional flow duration curves developed for one catchment may be transferred to another in same region if they are in similar rainfall zones and it can be assumed that the relative distribution of discharges within an annual run-off hydrograph will be similar.

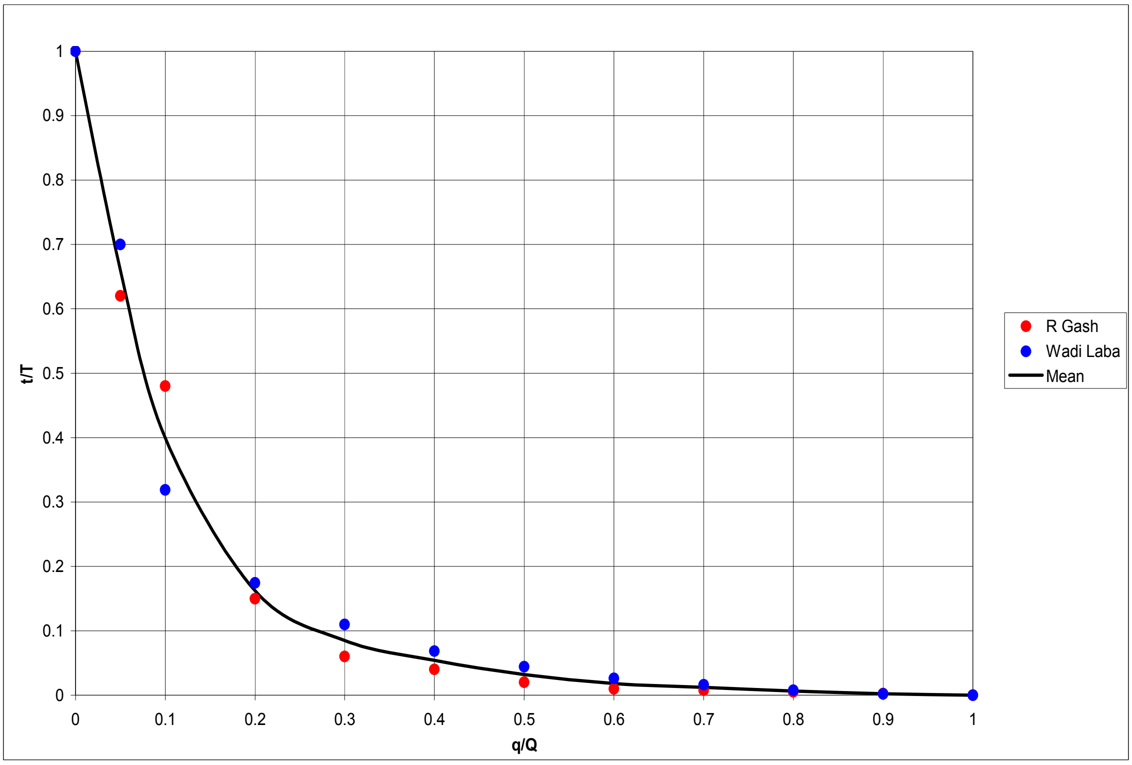

Figure A2.1 Non Dimensional Flow Duration Curve

Curves like those shown in Figure A2.1 can be used to estimate of the proportion of the annual flows that would be diverted from a wadi for different ratios of q/Q, where q is the selected intake capacity. The calculation assumes that all the flows less than the q/Q will be diverted and that diversion will be at the intake capacity q/Q when wadi discharges are higher than the diversion capacity. Diversion efficiencies calculated using these assumptions with the mean curve shown in Figure A2.1 are tabulated below.

Table A2.1 Proportion of annual flows diverted

Diversion capacity ratio q/Q	Percent of Annual Flow Diverted
0.1	54.3
0.2	76.8
0.3	86.6
0.4	92.2
0.5	95.6

The table illustrates the predominance of lower flows in the annual run-off in spate rivers, that in this case do not include significant periods of seasonal base flow. More than half the annual discharge could be diverted with a canal intake capacity set at 10 percent of the mean annual flood discharge, while an intake with the capacity to divert 50 percent of the mean annual flood discharge would divert 96 percent of the annual run-off. Of course reductions to the theoretical diversion efficiency tabulated above are needed to account for the real world, where canal and sluice gates at an intake have to be manually operated, often at night, in response to rapidly varying spate flows.

If the regional data needed to prepare a non dimensional flow duration relationships is not available approximate estimates of the proportion of the wadi flows diverted to canals can be derived using farmers knowledge of the number and sizes of floods and the shape and duration of typical flood recessions. The procedure involves assembling a ”representative” sequence of flood hydrographs and determining the proportion of the wadi flows that might be diverted for a range of intake capacities. If multiple intakes are to be used bed seepage losses between the intake locations should also be taken into account.

When the flow volumes diverted during the cropping season have been established the area that could be irrigated can in theory be estimated by irrigation engineers and agronomists, taking account of the crop water requirements and conveyance and irrigation efficiencies. However farmers will have their own views on the command areas that they are prepared to develop and these may not coincide with areas derived from rather simplistic calculations relying on assumed crop water requirements and diversion and conveyance efficiencies. In existing schemes estimates of potential cropped should at least be verified by comparison with currently cropped areas.

It is also be necessary to make an estimate of the likely variations between years. When data is not available this can be achieved by assuming that the annual run-off volumes are approximately proportional to the numbers of floods that occur and using farmers estimates of flood numbers for years with different return periods.

A2.3 Design flood discharges

Estimates of extreme flood discharges for specified return periods are needed to design weirs and intakes. Several methods can be used:

- Analysis of long term records of measured flood discharges.
- Analysis of synthetic long term run-off data derived from stochastic modelling.
- “Rational” methods based on a “design” rainfall intensity, a time of concentration derived from catchment parameters and a run-off coefficient that depends on catchment conditions.
- Regional flood frequency relationships.
- Slope area calculations to estimate the size of the largest historical flood that has occurred, for which local informants can provide a reasonably reliable estimate of the flood water level.

In practice the first method is virtually never feasible as long term flow data only exists for a small number of wadis world-wide. The second would only be considered for large projects that have the resources to commission specialised hydrological modelling. Rational methods are used in some areas, for example Balochistan, but require information on catchment characteristics to select appropriate run-off coefficients and rainfall intensity, data that is not available in the regions where many spate irrigation systems are located.

Regional flood frequency relationships are widely used for flood estimation in un-gauged catchments. They are derived by pooling data from gauged catchments within hydrologicaly similar regions, to develop a dimensionless flood frequency relationship that can be applied to un-gauged catchments in the same region.

The mean annual flood discharge (MAF) for the wadi being considered has to be known in order to use the regional flood frequency method.

A range of empirical equations for predicting MAF are available, see Table A2.2

Table A2.2 Methods for estimating MAF

Method	Equation	Note
Binnie (1988)	$MAF = 3.27 \times CA^{1.163} \times MSL^{-0.935}$	Regional flood formula developed or wadis in Southern Yemen
Bullock (1993)	$MAF = 0.114 \times CA^{0.52} \times MAP^{0.537}$	Developed using data from forty three semi arid catchments in Botswana, Zimbabwe South Africa and Namibia
Nouh (1988)	$MAF = 0.322 \times CA^{0.56} \times ELEV^{0.44}$	Developed from regressions on data from 26 gauging stations
Farquharson *et al* (1992)	$MAF = 0.172 \times CA^{0.57} \times MAP^{0.42}$	Developed from 3637 station years of data collected from arid zones world-wide.

In the table:

MAF = Mean annual flood peak discharge (m^3/s)
CA = Catchment area (km^2)
ELEV = Mean catchment elevation (m)
MSL = Main stream length (km)
MAP = Mean annual precipitation (mm)

Farquharson *et al* (1992) also present relationships for eight separate regions and also for each region regressions using catchment area only.

If relationships for the specific local region are unavailable the Farquharson *et al* (1992) mean relationship listed in the table can be used to estimate MAF. However as estimates derived using any of these equations may have a high standard error, it is recommended that estimates of MAF are at least verified using estimates of the discharges of historical floods. This is discussed later.

Many regional flood frequency relationships are available. We suggest using the Farquharson *et al* (1992) relationships, that were developed from a large, (3637 station years), world wide arid and semi arid zone data set. The design flood for the required return period is calculated by multiplying the MAF by a growth factor for the "design" return period selected from Table A2.3.

Table 2.3 Flood growth factors

Country or region	Growth factor 50 year return period	Growth factor 100 year return period
Algeria / Morocco / Tunisia	4.30	5.83
Botswana / South Africa	4.70	6.51
Iran	3.70	4.81
Jordan	4.07	5.27
Queensland	4.82	6.53
Saudi Arabia / Yemen	4.84	6.66
USA (SW)	4.45	6.34
Caucasus / Central Asia (SW)	4.27	5.61
All arid and semi arid regions MAP <600 mm	4.51	6.15

A2.4 Incorporating local information to improve estimates of MAF

The reliability of estimates of MAF can be improved by making use of flood discharges calculated from historic water levels at or close to the location of new or improved intakes. The procedure involves obtaining information locally on the maximum wadi water level that occurred in the largest remembered "historical" flood and the number of years that the flood level was not exceeded, (sometimes taken as the period since the historic event occurred). The flood water level is used, with a channel survey and an assumed value for the channel roughness coefficient, to derive an estimate of the peak discharge using a slope area calculation. The approximate return period for the "measured" event can be estimated if it is assumed that the probability of a flood of the given magnitude occurring in n years is 0.5, when:

$$T = 1/(1-0.5^{1/n}) \qquad (A2.3)$$

where:
T = Flood return period (years)
n = number of years over which the flood level was not exceeded

Using the growth factors for the appropriate return period from Table A2.4 the ratio between the flood magnitude at the estimated return period and the MAF and hence an estimate for MAF, can be obtained. The estimate for MAF is then used to determine the design flood discharge for the appropriate design return period. (The procedure is illustrated with an example given following Table 2.4.)

A2.5 Estimating sedimentation rates on spate irrigated fields

In existing schemes past increases in field levels can be assessed from the thickness of alluvial sediment deposits and the number of years that the scheme has been diverting water. This provides a guide to the expected future rates of rise of field levels that will need to taken into account when the command levels for improved intakes and other hydraulic structures are being determined.

For new schemes, particularly in regions that do not have nearby existing spate irrigated areas, estimating future command changes is more difficult. However approximate estimates can be made if information is available on catchment sediment yields, or the sediment concentrations in floods.

Catchment sediment yields, ($t/km^2/y$), can be converted to a sediment concentration by weight in ppm by dividing the product of catchment area and the sediment yield by the annual run-off volume in million m^3. Sediment concentrations in floods can be measured taking frequent regular surface bottle samples in floods and in the simplest form of analysis by averaging the sediment concentrations in the bottles. Care should be taken to ensure that averaged samples are collected during flood flows.

The annual rise in the command levels of upstream fields can then be estimated from:

$$RISE = N \times D \times Conc / (1.4 \times 10^6) \qquad (A2.4)$$

where;
RISE = Annual rise in the level of the upstream fields (m)
N = Number of irrigations
D = Depth of water applied per irrigation (m)
Conc = Sediment concentration by weight (ppm)

A2.6 Sediment size data

The need to control coarser sediments that settle in canals is discussed in Chapter 10. Sediment transport computations carried out to design sediment control structures are too complex to be included in these guidelines. However they are based on wadi bed sediment size distributions. Methods used to collect the sediment size data needed to carry out these calculations and to estimate the roughness coefficients of spate rivers with large bed materials are described in the next section.

A2.7 Slope area estimates of flood discharges

The Manning equation is usually used to compute discharges from water level, cross section(s), the water surface slope, (often assumed to be the same as the bed slope) and an estimated Manning roughness coefficient, which for wadis with coarse bed material is often taken as 0.035 or 0.04.

Calculations are carried out for a reasonably uniform and straight wadi reach, located close to the actual or proposed intake. Sites should be selected using the following criteria:

- Local information is used to make a reliable estimate of the water levels observed during a historic flood at the site.
- The length of reach should be greater than or equal to 75 times the mean depth of flow.
- The fall of the water surface should exceed 0.15 m from one end the reach to the other.
- The flow should be confined to one channel at the flood level with no flow bypassing the reach as over-bank flow.
- Application of the flow resistance equation requires that the bed should be largely free of vegetation and that the banks should not be covered by a major growth of trees and bushes. Sites with bedrock outcrops should also be avoided.

It is difficult to satisfy all the above criteria and some compromise is usually necessary.

The selected reach is surveyed to establish at least one cross section and the bed slope. (Usually three cross sections, at the start, middle and end of the reach are surveyed.)

The maximum water flood water level is levelled to the same datum used for the cross sections surveys.

Calculations can be carried out using the Manning equation[22]:

$$Q = (1/n) \times A \times R^{0.67} \times S^{0.5} \qquad \text{(A2.5)}$$

where
Q = discharge, m^3/s
A = Cross sectional area of the flow, m^2
R = Hydraulic radius, A/P, where P is the wetted perimeter of the cross section, m
S = the slope of the channel
n = Manning roughness coefficient

Mannings coefficient is tabulated for a range of channel conditions in most hydraulic text books. For Wadis with coarse bed materials it is often taken as 0.035 or 0.04.

An alternative equation for Wadis with coarse bed sediments, Bathurst (1985) predicts the channel roughness coefficient from the size of the bed material and has been successfully applied to estimate flood peak discharges in Yemen Wadis. The equation is:

$$Q = A \times D^{*} \times (g \times R \times S)^{0.5} \qquad \text{(A2.6)}$$

where:
Q = discharge, m^3/s
A = Cross sectional area of the flow, m^2
D* = $(5.62 \times \log(d/D_{84}) + 4)$
R = A divided by the wetted perimeter of the flow, m
S = the slope of the channel
d = mean flow depth (approximately the same as the hydraulic radius, R), m
D_{84} = the size of the bed material for which 84 percent of the material is finer, m
g = acceleration due to gravity, 9.81 m/s^2

The bed material size grading and hence D_{84} can be determined by sieving large volumes of bed material taken from shoals of coarse sediments located within the slope-area reach, which are assumed to represent the bed material in high discharge flows.

Sampling of bed material in coarse-grained channels requires a very large sample size to accurately represent the sediment distribution, when the surface layers consist mostly of gravel cobbles and boulders a randomised point counting method of the bed material can be used as an alternative to sieving. This can be achieved using a random walk to select stones for measurement:

- Starting at the centre of a shoal of coarse sediment and take one pace in a random direction and select the pebble/gravel/cobble lying directly at the end of your shoe.

- Pick up and measure the intermediate axis of this stone in millimetres.

[22] Calculations can be conveniently carried out using the “irregular cross section” option in the DORC design tools section of HR Wallingford’s “SHARC” sediment management software. The software and manuals can be downloaded at http://www.dfid-kar-water.net/w5outputs/software.html.

- Repeat, changing direction after each pace so that sampling is random and taking care not to look at the wadi bed when pacing. Avoid the temptation to "select" large gravels and cobbles. Ignore sediments smaller than 1 mm.

From these measurements a grading curve for the bed material can be produced by ranking the sizes of the intermediate axis in ascending order and plotting against a cumulative percent by number. The number of measurements needed depends on the range of sizes being sampled, but generally one hundred measurements will provide sufficient accuracy. Ideally this procedure should be repeated several times at different shoals and the representative D_{84} size taken as the mean of the individual D_{84} sizes.

For large canals with very coarse bed material either of the methods listed above can be used to estimate discharges from water levels. For channels or canals with sand beds an alluvial friction predictor is recommended to estimate channel roughness from bed material size and hydraulic conditions. One of methods is available in the design tools "DORC" option of HR Wallingford's SHARC sediment management design software are recommended.

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Table 2.4 Flood growth factors (From Farquharson *et al* (1992) for the region Botswana / South Africa)

Flood return Period, Years	Growth Factor
5.0	1.3
6.0	1.5
7.0	1.7
8.0	1.8
9.0	1.9
10.0	2.1
12.0	2.3
14.0	2.5
16.0	2.7
18.0	2.8
20.0	3.0
22.0	3.1
24.0	3.3
26.0	3.4
28.0	3.5
30.0	3.7
32.0	3.8
34.0	3.9
36.0	4.0
38.0	4.1
40.0	4.2
42.0	4.3
44.0	4.4
46.0	4.5
48.0	4.6
50.0	4.7
100.0	6.5
150.0	7.8
200.0	8.9

Example calculation

For this example we assume that there is an estimate of the discharge of a historic flood available from a slope area calculation based on local information on the maximum water level observed in the last nine years. The flood discharge calculated from a slope area calculation is 250 m^3/s.

As the flood discharge was not exceeded for nine years, n = 9. From equation A3.3, T=13 years.

From Table 7 the growth factor for 13 years is 2.4, hence the MAF derived from the slope area flood discharge is:

250/2.4 = 104 m^3/s
The 1:100 return period design flood will be 104 x 6.5 = 677 m^3/s

Annex 3 Agronomy – statistics

Table A3.1 Range of crops grown in spate irrigated areas in Eritrea, Ethiopia, Pakistan Yemen and Tunisia

Country/region	Range of crops grown	Reference
Eritrea		
Eastern lowlands	Sorghum and maize. Sorghum the most preferred crop and it is widely grown in the northern part of the eastern lowland. Maize ranks second and is widely grown in the southern part of the eastern lowlands. Other crops grown include pearl millet, cotton, sesame, groundnut, tomato, pepper, okra, kerkede and watermelon.	Ogbamichael (2004)
Sheeb area	Main crops – sorghum (hijera variety), maize. Minor crops – pearl millet, sesame, groundnut and some vegetables.	Tesfai (2001)
Ethiopia	Major crops are sorghum, maize, millet, cow pea and horse beans. Mainly local varieties that are drought resistant.	Michael (2000a)
Pakistan		
Kachhi District, Balochistan.	Sorghum, mung bean, moth bean, melons, rapeseed.	MacDonald (1987a)
Lasbela District, Balochistan.	Sorghum, mung bean, sesame, guar, castor, mustard or rape.	MacDonald (1987b)
D.I. Khan, Balochistan	Wheat, gram and mustard (sarsoon) in rabi. Sorghum and millet (joiwar and bajra) in kharif.	Khan AB (1990)
Rod-kohi area in D.I. Khan, Balochistan	Sorghum, millet and sweet melon (spring). Sorghum, millet (summer); late summer, local mustards introduced into summer crops. Wheat, gram (chickpea), rape/mustard (winter).	Khan M (1990)
Piedmont Plains (Sulaiman Range)	Wheat, sorghum, millets.	Khan and Rafiq (1990)
D.I. Khan	Gram, wheat, barley (rabi). Bajra, jowar (cherry), mung bean (kharif).	Wadud and Ahmad (1990)
Chandia, Balochistan	Basic farm system of area fodder sorghum and livestock. Combined with pulses, oilseed and wheat. Minor crops – coriander, radish and melons.	Halcrow (1993a)
Nal Dat, Balochistan	Sorghum, fodder guar, pulses (masoor or mash) (kharif). Wheat, some oilseed (rabi).	Halcrow (1993b)
Kharan, Balochistan	Wheat, sorghum, melons.	BMIADP (1994)
Balochistan	Mainly local cultivars – drought-resistant sorghum, millet, wheat, pulses, cotton and oilseeds.	van Steenbergen (1997)
Toiwar, Balochistan	Wheat, barley (rabi season). Mash and maize (kharif season).	Halcrow (1998)
	Maize, melons, sorghum, cumin, pulses (kharif season).	Rehan (2002)

Country/region	Range of crops grown	Reference
Yemen		
Wadi Rima	Two main cereal crops – sorghum and Bulrush millet. Lentils, cowpeas, beans and watermelons.	Goldsworthy (1975)
	Sorghum, Bulrush millet, cotton, sesame, maize and cowpeas	Makin (1977a); Pratt (1977)
Wadi Mawr	Sorghum, cotton (main crops).	Tipton and Kalmbach (1978)
Abyan Delta	Cotton, sesame, sorghum, water melon, millet, groundnuts. Bulrush, millet and groundnuts are grown unofficially.	WS Atkins (1984)
Wadi Ahwar	Long staple cotton, cereals (sorghum and millet), vegetables and melons.	Girgirah *et al*. (1987)
Wadi Rabwa	During study period cereals (sorghum, maize and millet) were grown on 52% of total land area, sesame on 5%, fodder (sorghum/pulse) on 29% and cotton (medium staple) on 2%.	Girgirah *et al*. (1987)
Tunisia		
	Nouael II Project	wheat, olive, almond

Table A3.2 Crop yield in spate irrigated areas of Eritrea Pakistan and Yemen

Country (region)	Crop	Yield (kg/ha) (spate irrigation)	Yield (kg/ha) (perennial/ground-water irrigation)	Reference/comments
Eritrea				
Sheeb area	Sorghum (1997/98 production year)	1,200–1,500 (main crop) 700–1,000 (ratoon crop)		Tesfai (2001)
Sheeb area	Sorghum (average grain yield in good season)	1,500 (1998) 2,000 (1999) (for seeded crop) 800–1,000 (ratoon crop)		Tesfai (2001) National average yield of sorghum (rainfed conditions) estimated to be 615kg/ha (FAO, 1997, cited in Tesfai, 2001)
Pakistan				
Balochistan (Kachhi District)	Wheat	450 (lowest)	700 (lowest)	MacDonald (1987a)
		1,200 (highest)	2,770 (highest)	
		600 (typical)	1,900 (typical)	
Balochistan (Lasbela District)	Sorghum in mix	290 (lowest)		MacDonald (1987b)
		1,380 (highest)		
		550 (typical)		
	Castor	395 (lowest)	1,480 (lowest)	
		988 (highest)	1,980 (highest)	
		495 (typical)	1,680 (typical)	
	Mung	270 (lowest)		
		550 (highest)		
		330 (typical)		
	Sorghum fodder	15,000 (lowest)	5,930 (lowest)	
		48,000 (highest)	32,000 (highest)	
		25,000 (typical)	17,600 (typical)	
D. I. Khan, Balochistan	Gram	789		Wadud and Ahmad (1990)
	Wheat	1706		
	Barley	905		
	Bajra	564		
	Jowar (Cherry)	485		
	Mung bean	485		
Balochistan	Wheat	450–900		Cited in van Steenbergen (1997)
	Sorghum	360–550		
	Pulses	200–500		
	Cotton	360–620		
	Oilseeds	150–350		
Balochistan (Toiwar Flood Irrigation Scheme)	Wheat	164		Halcrow (1998)
	Barley	213		
	Maize	125		
	Mash	96		

Country (region)	Crop	Yield (kg/ha) (spate irrigation)	Yield (kg/ha) (perennial/ground-water irrigation)	Reference/comments
Yemen				
Wadi Rima	Qaira (for grain) (variety of sorghum)	900 (average) 1,500 (high)	1,300–2,250	Goldsworthy (1975)
	(Seed) cotton	250	450	
	Sesame	250	600	
Coastal regions of Yemen (the former PDRY)	Cotton: Extra long staple	146		Mu'Allem (1987)
	Cotton: Medium Staple	251		
	Sorghum and millet	145		
	Sesame	82		
	Melons	1,632		
	Groundnuts	202		

Table A3.3 Yield responses (kg/ha) of spate irrigated crops to nitrogen fertiliser and improved cultural practices in the coastal region of Yemen (in the former PDRY)

Crop	Long Staple Cotton kg/ha	Medium Staple Cotton kg/ha	Sorghum/ Millet kg/ha	Sesame kg/ha	Melons kg/ha	Groundnuts Shelled Seed kg/ha
Treatment						
Nitrogen at 9.3kg/ha) and improved agricultural practices	221	339	212	121	2482	263
Control yield (kg/ha)	147	226	151	81	1711	202
Increased yield over control (kg/ha)	74	113	61	40	770	61
Increased yield over control (%)	50	50	40	49	45	30

Note: (8 seasons average, 1975/76 – 1982/83) (Mu'Allem 1987)

Table A3.4 Cropping intensities in spate irrigated areas of Eritrea Pakistan and the Yemen

Country/region	Cropping intensity (%)	Notes	Reference
Sheeb area, Eritrea	165		Tesfai (2001)
Pakistan			
Balochistan (Kachhi District)	30–40	Typical overall cropping intensity	MacDonald (1987a)
	90–120	Cropping intensity for irrigated areas – depending on the small amount of sequential cropping of wheat and April planted fodder.	
	150–180	On land that is well and regularly watered, when a sorghum-mung-moth crop and an early sorghum crop are grown back to back.	
Balochistan (Lasbela District)	30–60	Typical values in sailaba areas can rise to 120 percent overall in exceptional circumstances with very reliable flooding. Individual bundats may have cropping intensities of 200 percent at a time. In rainfed areas, cropping intensity can be as low as 20 percent.	MacDonald (1987b)
Yemen			
Wadi Rima	150	Spate irrigation has a high water use efficiency – though land at end of most canals receive spate on such an irregular basis that it is basically rainfed.	Makin (1977)
	230	Areas receiving regular spate irrigation (significant area of sorghum ratoons).	
	130	Areas receiving irregular spate irrigation (11 percent of area lies fallow in any one year) – success in cropping depends to an extent on timely rainfall.	
Wadi Mawr	“High”	Cropping intensities in main spate irrigation areas lying close to wadi are generally good because of the concentration of good arable lands and the more reliable water supply.	Tipton and Kalmbach (1978)
Wadi Bana and Abyan Delta	33–143	Reflects uncertainty of water supply – increases from north to south.	WS Atkins (1984)

Table A 3.5 Cropping patterns in spate irrigated areas in Ethiopia, Pakistan and Yemen

Country/region	Cropping patterns/Additional information	Reference
Eritrea	Crops usually sown from mid-September after flooding of fields has subsided, and harvested after 90–120 days.	Tesfai (2001)
Ethiopia	Two cropping seasons, locally known as Hagaya (September to January) and Ketena or Sorora (April to August). Normally plots are double-cropped under mixed cropping and ratooning system. Usually up to three types of crops (if not varieties) are intermixed in one cropping season.	Michael (2000a)
Pakistan		
Kachhi District, Balochistan.	Mixed crop of sorghum, mung bean and moth bean (sown after summer rains in July, Aug and Sept). Spring plantings of sorghum and melons made whenever possible. Rapeseed sown after late summer rains, important in some areas. Melons grown on one Feb/March flooding. Wheat only sown when there are late floods, particularly in late August and Sept. Main crop of sorghum sown as soon as possible after first summer floods. Rare for these crops to receive a second watering; farmers prefer to expand acreage with subsequent storm water. Irrigation priorities: sorghum-pulses, mustard, wheat.	MacDonald (1987a)
Lasbela District, Balochistan.	Sorghum, mung bean, sesame and sometimes guar sown on early floodwater (July-August). Castor – sown on floodwater that arrives Aug/Sept. Late water stored to grow rape in December (mustard rarely grown – insufficient moisture). Spring sowings of mixed mung and sorghum or guar as monocrop made if sufficient water (usually grown as fodders). Irrigation priorities: castor, sorghum + guar, mustard.	MacDonald (1987b)
Rod-kohi area in D.I. Khan, Balochistan	Long planting season – Feb-Aug for spring and summer crops; Oct-Dec for winter crops.	Khan M (1990)
Chandia, Balochistan	Basic farm system of area fodder sorghum and livestock is combined with pulses, oilseed and wheat. Sorghum – high value when grown for fodder, often interplanted with pulses, mainly mung. Sorghum ratooned – high return on investment. Wheat grown on finer textured land (wheat riskiest crop).	Halcrow (1993a)
Nal Dat, Balochistan	Planting time for kharif crop June/early July. Crop harvested Sept-Oct. Rabi crop sown in Oct, harvested in April/May.	Halcrow (1993b)
Kharan, Balochistan	Wheat sown Oct-Dec; no wheat grown unless there are floods. Wheat harvested April-May. In drier years, wheat and sorghum used for fodder.	BMIADP (1994)
Balochistan	Early monsoon floods used to grow sorghum; subsequent floods used for oilseeds. If monsoon arrives late, moisture stored and a wheat crop grown.	van Steenbergen (1997)

Country/region	Cropping patterns/Additional information	Reference
Toiwar, Balochistan	In the Kharif season cropped area is restricted due to shortage of water.	Halcrow (1998)
	Melons and pulses more drought resistant; maize sensitive to water stress.	Rehan (2002)
Yemen		
Wadi Rima	Lentils, cowpeas, beans and sometimes watermelons sown in the rows between the millet, if farmer thinks soil moisture sufficient.	Goldsworthy (1975)
	Sorghum most widespread and profitable crop (75 percent of total value of crop production in an average year). Bulrush millet – superior drought tolerance. Maize – locally important. Cannot be reliably grown under single-spate irrigation, but popular under more regular wadi irrigation. Cowpeas undercropped beneath both sorghum and maize. Cotton main cash crop. Usually several floods in March-May, this allows production in most years of early subsistence crop of sorghum or millet. Sesame – less important, but is apparently expanding under spate and pump irrigation.	Makin (1977a); Pratt (1977)
Coastal areas of the Yemen (in the former PDRY)	Two distinct flood periods – Seif (March-May) and Kharif (July-Sept). Seif floods permit the cultivation of a few field crops on a limited area. Crops include melons and sorghum, either as grain-cum-fodder if left till harvest, or green fodder if harvested 50-60 days after planting. Kharif floods permit the cultivation of several field crops on a larger area. These crops include the main cash crop (long and medium-staple cotton), sorghum, millet, sesame, melons and more recently, groundnuts (on a limited area).	Mu'Allem (1987)

Annex 4 Engineering in spate schemes

A4.1 Introduction

This annex describes some of the more technical aspects of the design of spate diversion and water control structures. It is intended to add to the design advice found in irrigation handbooks and manuals that mostly refers to the design of perennial irrigation systems.

A4.2 Improved traditional intakes

Improvement of traditional intakes offers the advantage of no change to the existing canal system and probably no change to the water rights. The basic objective is to reduce the costs of rebuilding and maintenance, which may have to be carried out after every flood. There are many options for improvement, which depend on site location and the available resources.

Traditional intakes are constructed from locally available materials. Large embankments (diversion bunds) are constructed with animal powered scraper boards, but this type of equipment cannot easily handle coarse gravel and cobbles. Diversion bunds are found on lower reaches of wadis, where the bed slopes, bed material sediment sizes and the flood peak discharges, are all lower than at the mountain fronts. Traditional diversion spurs in the upper wadis tend to built of brushwood (acacia bushes interlock very well) weighed down with hand-placed stones or finer wadi bed sediments. Other forms of construction are used for example tree trunks. Here the core of the deflecting spur is made from tree trunks, partly buried in a line of holes set out along the alignment of the spur. Brushwood is placed in between the piles. The upstream side of the deflector, exposed to the full force of the flood, is armoured, where available, with boulders and cobbles. The structure is further strengthened by scraping sediments from the river bed to cover the upstream and top part of the deflecting spur. A third form of construction uses interlocking cobbles and boulders collected from the river bed. (See also Box 10.2 in chapter10.)

The relative durability of the various forms of traditional intake, in terms of damage, suffered and the number of times they might be expected to be re-constructed in a “normal” spate season in Eritrea is reported in Haile (1999).

Table A4.1 Durability of traditional and gabion diversion spurs

Type of diversion spur	Estimated damage as percent of initial cost during normal spate season	Number of repetitions of re -construction during normal spate season
Mixed river sediments and brush wood (average)	70	2-4
Stone	50	1
Gabion	20	Can last for up to 5 years

For improved diversions using traditional materials a stone spur, or where gabions are available to farmers, a gabion spur seem to offer the best durability. Both these types need large sediments to be available in the wadi bed and thus would be restricted to upstream diversion sites. An alternative at either upstream or downstream sites is to use a bulldozer to scrape ups a more substantial spur.

Gabions are often used, where there is suitable stone, but have the disadvantage that the wire materials are not often locally available and have to be imported. Gabions are vulnerable to damage where high flows occur in wadi sections that transport large bed material sediment loads. The gabion wires are vulnerable to abrasion by the coarse bed material and may be snagged by large trash. A thin protective skin of concrete, that cracks to retain the inherent flexibility of gabion structures, can be provide some protection, but the useful life of gabion structures even when protected with a concrete skim will probably be quite short at the most exposed sites in upper wadis.

For more permanent structures, the preferred construction materials and forms of construction should still use locally available materials and skills. This is particularly important for smaller works that are to implemented by farmers. Designs that can be constructed using local materials and skills can be widely replicated in the future, without external support.

Walls of masonry, mass concrete (possibly using selected sand/gravel wadi bed material) or concrete block work (if local block production capacity exists) may be preferable to reinforced concrete, as a lower level of construction skills are required and they are normally less expensive.

Where the spate irrigation system is large, the most cost-effective construction materials will change with distance from the mountains. Masonry may be cheapest at the upstream end, near the mountains and mass concrete cheapest at the downstream end, where only sand and gravel is available from the wadi bed. However the overall design of structures would be unchanged. It is often better to retain a traditional intake where frequent relocation is necessary on account of an unstable wadi channel or rapidly rising field levels and limit improvement to provision of access to machinery for rebuilding of temporary works.

When improved and more durable structures are used it becomes important to limit the flows allowed to enter canals. The most basic control is a head regulator structure without gates. In its most simple form this can be a rectangular opening with two side walls constructed of suitable materials (masonry, concrete or gabions) and will be most effective where the maximum flood levels in the wadi are relatively low.

The next development is to design the head regulator to act as on orifice once the design flow is reached by providing a breast wall over the opening. The bottom of the breast wall should be at the design water level. Where land levels and canals are rising it may be appropriate to construct the bottom part of the breast wall in removable panels (concrete or steel beams) that can be taken out to compensate for rising bed levels and maintain the design flow depth. Breast walls and high abutments are most essential where the wadi channel is confined and flood levels high.

Rejection of excess flow can be used instead of, or in addition to, an intake structure.
A rejection capacity is normally provided as a side spillway in the first part of the main canal, where water can be easily passed back to the wadi. The effectiveness of the spillway is in proportion to its length. The spillway will be more effective if a further flow control structure is provided on the canal just downstream of the spillway because water level changes at the structure will then be much more sensitive to excess flow than in an open trapezoidal channel. An orifice control is the most effective means increasing rejection, with the top of the orifice set at spillway crest level.

A4.3 Permanent intakes with raised weirs and gates

A4.3.1 Requirements for permanent intakes

The following factors are important when new diversion structures are planned:

Command - It is essential to locate the diversion structure at an elevation that allows the diverted water to be supplied to the command area by gravity, including a conservative margin to allow for a futures rise in the levels of the fields and canal beds.

Type of foundation: - where possible diversion weirs should be founded on strong foundations preferably rock. However in most cases weirs have to be founded on permeable wadi bed materials. Provision of under drainage and weep holes should be sufficient to manage the risk of uplift pressures at these structures, without the need to provide very heavy structures designed to resist uplift solely by their weight.

Location on a shallow bend - The best location for a canal intake is on the outside of relatively mild wadi bend, just downstream from the section of maximum curvature. The deep-water channel is established at the outside of a bend during floods and this forms the low flow channel during flood recessions. Locating an intake at the outside of a bend helps to ensure trouble free abstraction of low flows and most traditional intakes are located at the outside of river bends for this reason. Although they have been adopted in some large spate systems double sided intakes, i.e. structures with canal intakes on both banks are not recommended. Ensuring that water flows to both sides of wide wadis when the diversion weirs are silted to crest levels usually requires active intervention in the wadi bed to construct channels or bunds, which rather defeats the object of constructing permanent structures.

A location on the outside of a bend can provide some sediment control benefits. Secondary currents generated at a bend in large floods sweep the coarse sediments that are transported on or near the channel bed towards the inside of the bend and away from the canal intake. This mechanism will only become important in large floods when a wadi is flowing at a reasonable depth over its full width. However the principle is used at intakes with curved channel sluiceways, see later.

The disadvantage of locating an intake at the outside of bend is that trash picked up by floods tends concentrate at the outside of a bend. The problem is worst at a very steep bends, see Figure A4.1.

Figure A4.1 Trash completely blocking a small new intake located on the outside of an excessively sharp (>90^0) river bend in Ethiopia

There are three basic options for managing trash:

- Encourage the trash to pass down the wadi through careful design.
- Detain the trash upstream of the intake (e.g. with a floating boom) where it will not significantly obstruct the flow.
- Allow the trash to pass through the intake and into the canal.

The third option is usually the most attractive. However, there is an upper limit to the size of trash that can be passed into a canal and once something becomes trapped, then it will obstruct the passage of smaller trash so that a blockage follows. The design of the intake structure should facilitate trash removal. (An example of a trash screen used at some new intakes in the Yemen was given in Chapter 10.)

Capacity to pass large floods. Conventionally a weir is designed to safely pass the long return period discharge selected as the design discharge. For diversion weirs, this is often taken as the 1 in 100-year return period flood discharge. In spate rivers where the flood discharge can be large this approach will usually require an expensive weir. It is common practice to design a short weir that will pass a smaller design flood, say the 1 in 10 year return period flood and to complete the diversion structure with a embankment or fuse plug. Floods larger than the weir capacity will overtop, erode and breach the embankment, limiting the maximum flow over the diversion weir.

Capacity of the canal head regulator. A head regulator for a spate irrigation system should have a large flow capacity as irrigation has to be carried in over the short periods that the rivers flow. Irrigation duties for spate irrigation are many times larger than adopted for perennial irrigation. The selection of intake and canal capacities at modernised intakes is discussed further in Chapter 4.

A4.3.2 Components of permanent diversion structures

A conventional diversion structure includes the following main components:

- Raised weir
- Gated scour or under sluice

- Gated canal head regulator
- Guide or divide wall.

Weirs

In perennial rivers with mild slopes raised weirs are needed to provide command for gravity irrigation. In wadis, which are much steeper than most perennial rivers, a high weir is not usually needed to achieve command. Moving an intake a short distance upstream, at the expense of a short additional length of canal, can provide additional command more cheaply. However a low weir is still used, for two reasons. The first is to stabilise the supply water levels. This is necessary in wadis, where often bed levels move up and down in response to floods and local bed levels can change by more than a metre as the low flow channels change their alignments. The second reason is to provide the head difference needed to operate a scour sluice.

In wadis coarse sediments settle in front of a new weir and the upstream bed level soon rises close to the weir crest level. The "pool" formed upstream from the weir is then lost. Unless the weir is correctly located, with the canal intake at the outside of a bend, or aggressive sluicing is carried out to attract the deep water channel towards the canal intake, the channel carrying flood recession flows can form on the "wrong" side of the weir. This makes diversion of low flows difficult or impossible without excavating channels across the wadi bed. The weirs on some spate diversion structures are constructed with a mild cross fall along the crest towards the canal intake, to encourage the deep-water channel to flow towards the canal intake.

Some examples from the Yemen are given below:

Table A4.2 Weir cross fall

Site	Weir cross fall	Note
Wadi Bana	1 in 400	Proposed for diversion weirs
Wadi Mawr	1 in 120	One quarter of weir at the intake side has the sloping crest
Wadi Rima	1 in 70	Diversion weir
Wadi Rima	1 in 33	Gabion bed sill, set at natural wadi cross slope at a bend

Stilling basins are required downstream from weirs to reduce high velocity flows to a velocity, which will not cause excessive erosion of the natural riverbed or the downstream channel. Without adequate energy dissipation there is a danger that a weir will be undermined. The cost of energy dissipation arrangements at a weir increases with increasing discharge intensity (discharge / unit width) and with increasing weir height. The general recommendation is thus to keep the weir height as low as possible consistent with achieving effective sluicing and also command over the life of the structure and also to design for a relatively low discharge intensity.

In large wadis shorter weirs spanning only part of a wadi and designed to pass a smaller "design flood", are used to reduce the costs. A beaching bund or "fuse plug", constructed from unconsolidated river bed materials, designed to overtop and scour out when wadi flows exceed the design discharge of the weir, completes the diversion structure.

The concept of incorporating a “weak” section in spate diversion structures, that fails to protect the diversion infrastructure from damage by very large floods has a very long history. In its modern guise as a “fuse plug” breaching bunds were incorporated at many new intakes in Yemen and Pakistan. In Yemen the fuse plugs incorporated in the Wadi Zabid diversion structures were considered to have “saved” the system when a historic flood occurred soon after the new intakes were constructed.

It is important that a fuse plug is designed to fail at a discharge that does not occur too frequently, or farmers will take steps to reduce the labour needed for frequent re-construction. In Pakistan, some fuse plugs have been concreted over by farmers. This will certainly have reduced the need for frequent re-construction, but at the risk of serious damage to the intake structure and weir if and when a historic flood occurs.

The probability that one or more flood events with a specified return period occurring over the design life off a structure is shown in Figure A4.2.

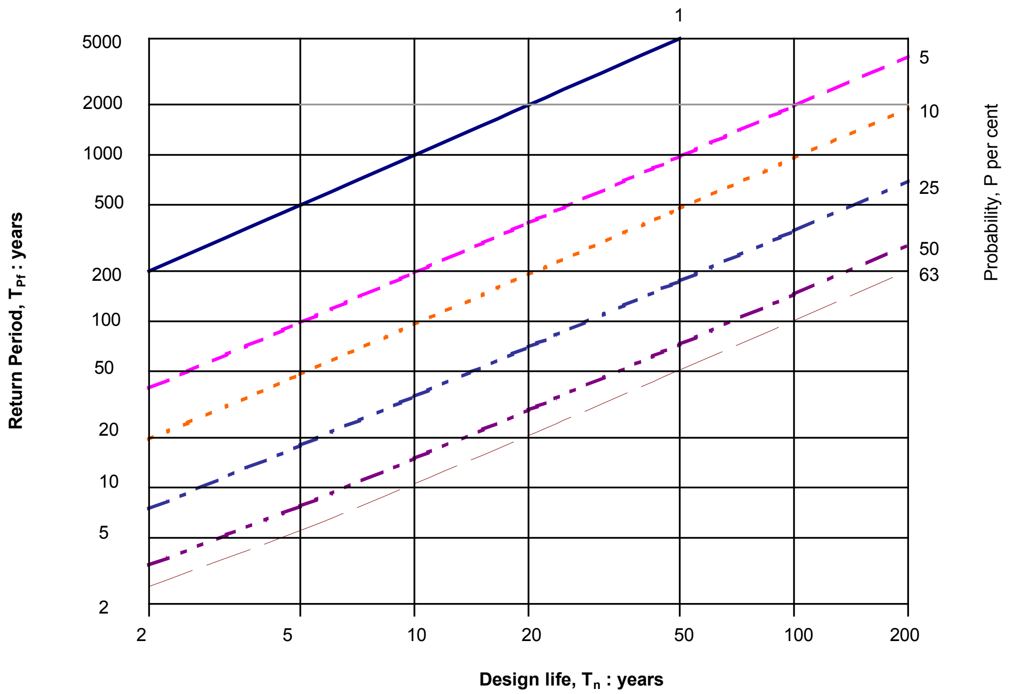

Figure A4.2 Probability of floods with a specified return periods being encountered

For example if a fuse plug is deigned to fail at a discharge equivalent to a 10 year return period flood then there is a 63 percent probability of one or more floods of this magnitude occurring over the design life. However there is appreciable probability of much larger floods will occur, for example a 10 percent probability of a flood with a 1 in 100 year return period.

As in general the hydrological analysis carried out to specify discharges with specified return periods will at best be approximate and in some case based on little more than intelligent guess work, a conservative approach to setting an appropriate failure discharge is necessary.

Scour sluice

Wadis transport very large concentrations of fine sands, silts and clays. These cannot be excluded from canal networks at an intake and are transported to and settle on, the fields. The smaller quantities of larger sediments, coarse sands, gravels cobbles in some cases, boulders that are transported at high wadi flows will settle in and block canals if they are diverted at an intake. The first step in minimising problems caused by the deposition of coarse sediments is to exclude as much of the large sediments as possible at the intake.

This is achieved by conducting as much as possible of the streambed load material transported at high wadi flows past the canal intake and through the diversion structure. Permanent spate irrigation head works thus incorporate a scouring sluice, located between the weir and the canal head regulator. The sluice is designed to provide a scouring action across the front of the canal head regulator and to carry as much as possible of the wadi bed load and some of the coarser fractions, carried in the lower layer of flood water past the intake and through the sluice. There are widely varying recommendations concerning the discharge capacity that should be provided at a sluice. For the curved channel sluiceway described later, the sluicing capacity is set at around 30 percent of the canal full supply discharge when then the water level in the wadi is at the weir crest level. Providing an excessive sluicing capacity is self defeating as it will induce very high velocities in the flows approaching the intake, that will pick up carry additional coarse sediments, some of which will be thrown into suspension and diverted to the canal.

The design and operation of scour sluices for spate schemes have important differences with the practices described in most irrigation engineering textbooks and design guides, which are based on perennial irrigation diversion practice. In spate schemes at low to medium wadi discharges all the flow will normally need to be diverted to the canal and the scour sluice will be closed[23]. When wadi discharges exceed the flow needed for the canal, the scour sluice gates could in theory be progressively opened to generate a sluicing action in front of the canal intake. As the canal entrance sill is set at a higher elevation than the sill of the sluice gates, some of the large sediments moving at or close to the wadi bed are then passed through the sluice. The canal abstracts water from higher elevations, where the sediments transported by the wadi flow are finer. In practice turbulence throws some of the coarser sediment into suspension and some gravel and coarse sands are usually also diverted to a canal even when a well-designed sluiceway is operated.

Manual operation of sluice gates, in rapidly varying spate flows so as to follow idealised gate operations rules, is seen in some O&M guides as difficult or impossible. Even if the structure is manned when a flood arrives, the flood peak will often have passed the intake before the gates can be fully opened. Apart from these practical difficulties the first priority of farmers is to divert as much water as possible during the infrequent flood events. They are usually extremely reluctant to open sluice gates, except during the largest floods, when high flows diverted to a canal threaten to damage canals and water distribution structures. Thus unless the water supplied via the sluice is needed for downstream diversions with water rights the operation of sluices in farmer managed systems can only be assumed in the largest floods.

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[23] The "still pond" method of operation frequently used at intakes in perennial rivers is not applicable in spate rivers.

The early experience from large new intakes in Yemen suggests that sluice gates should be constructed without a headwall to improve the throughput of sediment and trash. The sluice gate in this case must be capable of being raised above the maximum expected high flood water level and also designed to withstand the forces that would occur if the gate is left lowered and is overtopped in large floods. Cost considerations usually ruled out this approach except for the largest schemes.

The curved channel sediment excluder was used in several improved large spate irrigation intakes. This type of intake and sluice arrangement was developed to improve sediment exclusion in floods, by utilising the beneficial effects of a channel bend in excluding coarse sediment mentioned earlier. An artificial bend is created in a short converging channel constructed upstream from the sluice gates. The canal intake is located on the outer side of the artificial bend angled at about 30^0 with a small diversion angle. A typical layout for a curved channel intake is shown in Figure A4.3. (A recently constructed diversion structure including a curved channel sediment excluder in Eritrea is shown in Figure 10.16 of Chapter 10.)

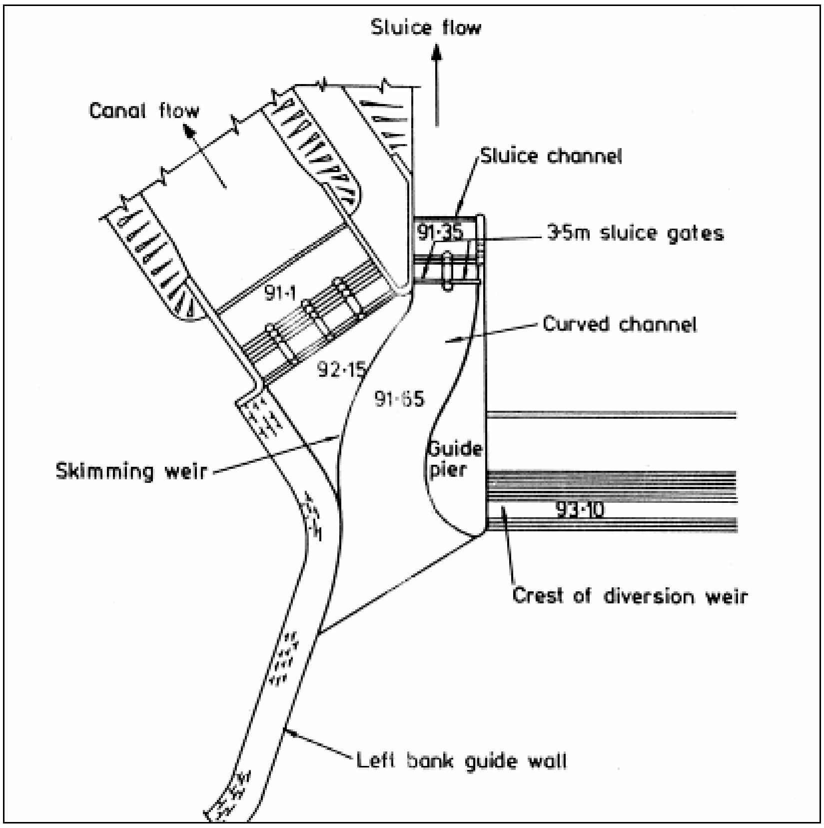

Figure A4.3 Layout of a typical curved channel sediment excluder

Canal head regulators

A canal head regulator or intake is located at the entrance of a canal and next to the scour sluice. Its functions are to:

- Regulate the discharges entering a canal.
- Limit the maximum discharge entering the canal to the design full supply discharge.

- When used in conjunction with a scour sluice to reduce the quantities of coarse sediments that enter the canal.

Head regulators are designed to pass the canal full supply discharge when the water level in the wadi is at the weir crest level. As mentioned earlier the sill level of the head regulators is set at a higher elevation than the sill level of the sediment sluice, so that the canal entrance acts as a skimming weir during periods of very high wadi flow, when the sluice gates should be opened. In spate intakes the width of the head regulator opening is usually kept approximately the same the bed width of the downstream canal.

Gated intakes provide the capability to regulate the flow into the canal and, if necessary (for example in an emergency, or for water allocation reasons), to close the canal. Gates should be largest possible size suitable for the means of operation, since intermediate piers at the head works increase the hydraulic losses and also catch trash during floods. Ideally, the gate openings should be sufficient to pass large trash since any blockage represents a loss of water for the farmers. Vertical gates are less expensive to manufacture than radial gates but require greater operating effort. Vertical gates greater than about 2m width are inappropriate for manual operation; whereas manually operated radial gates can span up to about 5m. Usually a breast wall is provided above the gate, with the bottom of the breast wall being set at the upstream water level required to give the design flow to the canal. This limits the maximum flow when the gate is open and minimises the size and weight of the gate. To ensure effective control of the discharges admitted to the canal, regulators should be provided with at least two gates. However provision for rising command levels over the life of a diversion structure should be made by constructing the breast wall so that it can be raised in stages.

Head regulators in conventional river intakes are frequently aligned with the gates at 90^0 to the weir axis, but this requires flows entering the canal to turn through al large angle which is far from ideal for sediment control. Much smaller diversion angles are recommended, see for example Figure A4.5, to minimise changes in direction in the flows diverted to the canal. As in spate systems intakes operate for most of the time with all or most of the wadi flow passing into the canal, the angle of diversion is only significant during short periods of high flows during flood peaks.

Divide wall

If a curved channel intake is not adopted then a short divide wall is constructed at right angles to the axis of the weir to separate the scour sluice from the weir. The long divide walls included in intakes designed for still pond operation in perennial rivers are not used in spate river diversion structures.

A4.4 Design of Spate canals

In spate systems the objective is to divert the maximum amount of water to the fields in the short time periods, often only a few hours, that significant spate flows occur. Water conveyance systems in spate schemes thus need very much larger canal capacities per unit area served than to those in perennial irrigation schemes. When spate systems are being improved it is prudent to provide canal discharge capacities that are similar to those estimated for the existing traditional canals.

Traditional canals in spate schemes are usually constructed without drop structures and are far steeper than conventional canals used in perennial irrigation systems. Canal slopes similar to bed slope of the wadi from which water is diverted and much steeper than canals designed by irrigation engineers in conventional irrigation systems are usual.

A canal network will already be in place when existing spate schemes are being improved. Improved canal networks, supplying water to controlled field outlets, can give better control and overcome some of the other disadvantages of the field to field water distribution system, but will probably also require a change in the way that water is distributed. This could have a large impact on existing water rights. Any improved system must ensure that irrigation can be carried out quickly, in the short periods that spate flows occur. Experience suggests that major modifications to canal systems of farmer managed schemes should not be considered unless there is significant siltation, scour, or canal breaching problems, or farmers request improvements. Any interventions should obviously be developed with the farmers, to ensure that that they understand and agree with the implications of any implied changes to water distribution, and, if new canals are proposed, agree to provide the additional land that will be needed, as this will almost certainly have to be taken from previously irrigated land.

Improved canals

In existing schemes, where canals are performing reasonably satisfactorily, the design of any new or extended canals should be based on the slopes and cross sections of existing traditional canals, derived from surveys. If the discharge capacity is to be changed, then the survey data can be used to select a canal design method that best predicts the existing canal slopes and dimensions. The selected method can then be applied to design the new canals. It is important to note that most conventional "regime" canal design methods presented in irrigation design guides were developed for canals in perennial irrigation systems that are operated within a fairly narrow range of discharges and have a small sediment input. This contrasts with the situation in spate canals, where the discharge varies rapidly over the full range of flows from zero to the maximum discharge. Sediment inputs are very large and canal designers are not free to set the canal cross section and slope to carry the required discharge, without also providing an appropriately high sediment transporting capacity. This rules out the use of most conventional canal design procedures. The Simons and Albertson and Chang canal design methods enable canals to be designed to carry high sediment loads and predict the wide shallow cross sections seen in spate canals and both have been used to design new canals in spate systems. (Both methods are available in HR Wallingford's SHARC sediment management software suite[24].)

Conventionally the peak or design discharge is used to determine the canal bed slopes and cross sections. If this is followed for spate canals there will be serious siltation problems at lower flows. This is because canals flow at their full design discharge for very short time periods. Most of the time the canal flow is very much lower than the peak discharge and a steeper canal bed slope is required for the lower flows to avoid sediment deposition. One recommendation is that about 70 percent of the peak discharge is used to determine the bed slope and bed width of spate canals when one of the canal design methods discussed later is used. The capacity to convey the maximum discharge is provided by increasing the depth and freeboard. There may be some erosion of the canal bed and banks when the flow in the canal is large, but as very high flows are maintained for short periods and will be carrying very high sediment loads; there is little chance of serious scour problems occurring.

[24] Can be downloaded free of charge at http://www.dfid-kar-water.net/w5outputs/ (from the software option via the index of outputs)

A4.5 Water control structures

New and improved canal water control structures for spate systems are discussed in Chapter 10. The design of new “engineered” structures is similar to those used in perennial systems, after accounting for the much large flows/ unit area served. The need to cope with rising command and the need for rapid operation in flashy spate flows generally rules out the use of stop logs to adjust flows.

Assisting farmers by providing better engineered versions of traditional structures, an example is given in Chapter 10, will often be the most appropriate strategy.

A4.6 Design Standards

The limited financial returns to spate irrigation may dictate corresponding low levels of investment. A challenge for the designers is to achieve effective improvements at low cost. Conventional design practice and criteria may often be inappropriate. Much can be learned from studying existing structures in the more advanced traditional spate irrigation systems.

Developed country design practice tends to combine a series of worst case loading with additional factors of safety, such that the risk of failure of a structure is extremely small. The probability of all the adverse conditions combining at the same time is also very small. A risk assessment and value engineering review should be included in the spate irrigation design process. This helps designer focus on the risk and consequences of damage or failure. Is it, for example, appropriate to design scour protection for a gabion structure for the 1 in 100 year flood when the life expectancy of the materials is certainly less, sometimes much less, than 30 years. Conventional irrigation structures are usually designed for continuous exposure to water with high ground water level conditions. Spate irrigation structures usually are subjected only to intermittent exposure to water with low ground water conditions (an exception may be diversion structures at the upstream end of the system). There may not be time for water pressure to build up behind walls and any water seeping under structures is likely to move downwards, rather than causing uplift pressures. In addition, maximum design water levels occur for short durations and groundwater levels around structures is unlikely to reach steady state conditions. These aspects are difficult to quantify and the best guidance to look at locally designed structures that have proved to be reasonably durable.

In order to create cost-effective designs for spate schemes it is necessary to carefully scrutinise conventional design procedures and assumptions. Aspects that might be considered include:

Scour

Potential scour usually calculated using the Lacey formula, which is simple but based on conditions in the Indian subcontinent. Its applicability to steep rivers with gravel beds and very high sediment loads is less certain. Sediment transport regime studies have indicated high sediment loads increase the threshold at which scour occurs and it is logical that the same principle applies to scour. For example, if a scour hole develops in the bed of a wadi transporting material of different sizes, the larger material will tend to fall into the hole and protect against further scour.

In some locations the scour protection tends to be provided to maintain appearance by preventing erosion of a channel bed or banks. To reduce costs, such protection can be reduced or eliminated provided that any scour will not endanger the integrity of structures or embankments. In other locations it is more cost-effective to deepen structure foundations or cut-offs instead of providing scour protection. For example the traditional drop structures in wadi Zabid in Yemen have deep foundations and no erosion protection. Scour holes tend to be in filled when the floods recede.

Wall Stability

Many conventional designs make extensive use of mass masonry walls. In general, the walls are mounted on base slabs for the whole structure, which eliminates the risk of wall foundation failure. Usually, the main destabilising force on a wall is water behind the wall. In most design situations, this loading is unlikely to become a threat. Where groundwater levels are low, then the tendency will be for any water moving behind walls to percolate downwards and only exert limited lateral force. An exception to this condition may be the drop wall of a drop structure where the canal water level is above the wall.

Wall stability will also be improved by the 3-dimensional nature of most structures where walls join to other walls, thereby improving overall stability. The drop wall of a drop structure is effectively a beam spanning two sidewalls and failure is unlikely to be from overturning. For structures in the main wadis a further issue is the time required to develop a destabilising water pressure during a flood event. The time required for sufficient water to percolate behind a wall to create a hydrostatic load is likely to be longer than the duration of high water levels.

Uplift

Uplift pressures can only develop where there is saturated ground. Where groundwater levels are not at, or close to, ground level, seepage water below structures will tend to percolate downwards and is considered unlikely to cause flotation of structures through uplift pressures.

Where uplift pressures may occur, drainage is the preferred solution. Al Arais and Ras Al Wadi weirs in southern Yemen are of relatively light construction with water emerging through drainage holes, and demonstrate that drainage is reliable alternative to combating uplift using mass. For smaller structures, uplift can usually be resisted by the dead weight of the side walls.

Seepage and Piping

Seepage beneath or around structures may occur where there is a difference in water levels between upstream and downstream. Seepage may occur irrespective of groundwater conditions if an easy seepage path exists. Cut offs installed to reduce seepage increase the potential uplift pressures. However, as noted above, the ground is rarely fully saturated and water will move downwards instead of exerting a large uplift force on the structure.

Seepage beneath diversion structures represents a loss of water, but is only damaging if it causes piping. (Piping is caused when seepage washes out soil from beneath or around the structure.) Traditionally, piping is prevented by carefully designed and constructed graded filters, which enabled water to be drained without washing out the soil.

However, the availability of geo textiles substantially reduces the design and construction effort and facilitates the emergence of any seepage without threat of damage.

Piping failures may occur at a structure – wall interface. Wing walls are provided to lengthen any seepage paths behind structure walls. Care must be taken during construction to ensure that walls are solid and do not contain voids and that backfill does not contain very permeable material.

A specific problem for spate irrigation design is where it is proposed to use an earth bund within a structure. If an earth bund is placed between two walls there is a real risk of seepage and piping failure occurring between the earth and the wall. The solution to this is to place the earth bund upstream of the structure so that there is a soil-to-soil contact.

Energy Dissipation

Conventional design of hydraulic structures gives considerable emphasis to achieving full energy dissipation within the confines of the structure. This can add substantially to the cost of the structures. In order to achieve cost-effective structures for spate irrigation, it is often appropriate to compromise on the extent of energy dissipation provided by one or more of the following:

- Examination of overall heads and velocities to ensure that there is energy to be dissipated. In many situations there is a need to keep velocities relatively high in order to transport sediment.
- Use of a dominant (50–80 percent of maximum) flow for the sizing of energy dissipaters.
- Provision of channel protection downstream of a structure to prevent damage from turbulent flows emerging from structures.
- Acceptance of scour downstream of structures in the knowledge that the high sediment loads tend to infill scour holes as the flow recedes.

Many traditional drop structures appear to use unlined plunge pools for energy dissipation. Given that structures have had to be periodically raised because of rising field levels, lined basin would eventually become buried.

A4.7 Construction Materials for Structures

There are four main alternatives for construction materials for “permanent” structures.

- Masonry
- Mass concrete
- Reinforced concrete
- Gabions.

Reinforced concrete requires close attention to construction quality to create a durable product. It is therefore not preferred except for items such a breast walls and bridge slabs.

Gabions are suitable in some locations. They are most suitable for remote sites where stone is available, because only the empty baskets have to be transported. They can be cost effective at other locations if stone plus gabion baskets of suitable quality are available and are not subjected to highly abrasive conditions in large wadis. There often some uncertainty about the quality of gabion materials available and they may not anyway be available locally at a price that farmers can afford.

Mass concrete and masonry are both assumed to have the same basic structural properties, so the choice between them depends on materials availability and ease of construction. Concrete in walls requires formwork which, if poorly constructed, will result in a poor quality finish.

In general, the preferred form of construction for structures is a mass concrete base slab with mass masonry walls. Cut offs are normally mass concrete cast into excavated trenches in order to form a good seal between the concrete and the ground.

Blinding concrete is not normally required under mass concrete foundations unless there is a need to form a firm working base. Soft ground should be stabilised either by replacement with better material or by ramming stones into the soft material. The cost of thick mass concrete structures can be reduced by using “plum” concrete, where up to 30 percent of the concrete is replaced by rocks typically 200–300 mm diameter and embedded in the pour.

Where technically feasible, designs are preferred that are easy to construct and use locally available materials This will make it easier for farmers to replicate the designs in the future, should they wish to build additional similar structures. Such structures also tend to be easy to repair.

A4.8 Construction Material for Erosion Protection

A range of materials can be used for erosion protection:

- Gabion mattresses
- Tipped rock
- Uncemented stone pitching
- Cemented stone pitching
- Pitching with other materials.

Gabion mattresses are often used for major structures. Stone pitching is preferred for minor structures, which may be built by farmers. Whether the pitching is cemented is usually determined by the farmers. Uncemented pitching over a geotextile is usually technically acceptable, but farmers often prefer cemented pitching to reduce the possibility of the stones being removed. This risk also applies to tipped rock, unless the rock is large and therefore unsuitable for manual placing.

A4.9 Sediment management in spate schemes

Spate irrigation systems have evolved, in some cases over centuries, to enable water to be diverted from unpredictable flashy flows carrying high sediment concentrations. The features of traditional intakes that enable them carry out this function successfully are:

- The diversion spurs or bunds are cut or breached when the flows entering off takes become excessive and thus very high sediment concentrations, carried by the larger flood flows, are not diverted to canals.
- Canals have very steep slopes and thus a high sediment transporting capacity.

- There are no permanent structures in canals to pond or retard flows, thus minimising the possibility of sediment settling on the bed.

Serious sediment problems have been encountered in some schemes where existing traditional intakes have been replaced with raised weirs and gated canal intakes. Problems include loss of control over low flow channels, resulting from the inevitable rise in bed levels upstream from a permanent weir and excessive canal sedimentation. Traditional systems do not usually suffer from these problems. The alignment of diversion spurs can be adjusted to follow changes in the location of low flow channel and bed scour in large floods maintains average bed levels. Canal sedimentation is minimised by the exclusion of high flows and the steep canal slopes.

The sediment concentrations that can be transported by a canal reduce as the discharge is reduced and also reduce, as the channel slope becomes flatter. Thus when a proportion of the flow in a wadi is diverted to a canal, where typically both the discharge and the slope are smaller than the wadi, the reduction in sediment transporting capacity results in sediment settling to the canal bed. If sediment loads are high, siltation will rapidly start to reduce the canal capacity and may block the canal. The objective of sediment control is to match the size range and sediment concentration of the sediments that are admitted to canals, to that which the canal can transport.

The sediment transporting capacity of a canal depends strongly on sediment size. For very fine sediments, the transporting capacity in canals is very large and silts and clays are usually transported through to the fields. There is no need to control sediments in this size range, which are anyway regarded as a valuable source of fertility by farmers. Coarser sediments, which can be transported at medium to large flows in the river, will deposit in the head reach of canals and should be excluded at the intake. The size of sediment that has to be excluded depends on the slopes and discharges of the canal and some other factors, but in spate schemes it is usually sufficient to exclude all sediments larger than coarse sand. The rest of this section is thus concerned with the management of coarse sediments, i.e. coarse sand, gravel and in some cases cobbles and small boulders.

Some exclusion by be achieved by operating a sediment sluice during flood peaks. The problem is one of conducting as much as possible of the stream bed load material through the diversion structure, thereby avoiding its expensive removal from the canal. As discussed earlier an irrigation head works should therefore incorporate a scouring sluiceway, between the weir and the canal head regulator. The performance of the sediment excluding sluiceway depends on both sediment sizes and hydraulic conditions in the wadi. It can be predicted, but the techniques involved are too complex to be described here. An excluder will only be operated during periods when the wadi flow exceeds the canal flow. Thus intakes will often be operated for considerable periods at low and medium flows without sediment exclusion. There is also the possibility that farmers will not operate the excluder at high flows, by not opening the sluiceway gate. Therefore some form of secondary sediment control is needed if canal sedimentation is to be minimised.

The canal sediment ejectors used in perennial irrigation systems are unacceptable for spate systems, as they require water to be wasted from the canal for sediment flushing and need control gates that would need to be continuously adjusted during floods. A simple sediment settling basin at the provided at the head of primary spate canals can be used to trap the coarser sediments that are diverted to a canal, before they settle in the canal system. A settling basin can be constructed by widening and deepening the canal reach at a point a little downstream from the intake, a distance of about 10 times the canal width, where the turbulence introduced at the head works has substantially decayed. The advantage of a small basin, over the alternative of allowing sedimentation in the canal, is that some deposition can be accommodated before the flow capacity of the canal is reduced and most subsequent de silting will be carried out at one location.

While flushed settling basins have been used in spate schemes operation can be problematical when a series of low to medium spates occur, filling the basins with sediment, but they cannot be flushed without diverting water than could be used for irrigation. This is unpopular with farmers. Mechanically excavated basins are often used but some care is needed to ensure that can be emptied when they are filled with saturated sediments. In Wadi Laba in Eritrea it did not prove to be possible to excavate a settling basin, as a bulldozer could not work on the wet unconsolidated sediments trapped in the basin. Machines that can work from the bank of mechanically excavated settling basin are needed in this sort of system, where a series of floods may occur within a few days, sediments may have to be removed when the canal is still flowing, or before the sediment deposits can dry out.

Annex 5 Native 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 stabiliser
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)
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

Botanical name	Common name	Economic uses
Withania coagulans	Paneer	
Zizyphys Mauritania	Ber	Timber, browse
Zizyphys nummularia	Mallah	Browse

Source: PARC/UNEP/ESCAP 1994

Annex 6 Summary assessment of two years of drought in Balochistan 1998–2000, based on Qazi (2001)

- A sharp decline occurred in the consumption of nutritious items as well as staple food intake. In many instances, the people had substituted their normal food items with inferior items. For instance, 33 percent villages reported reduction in staple food quantity, 57 percent villages reported reduction in nutritious items such as meat, milk and ghee and 66 percent villages reported substitution of normal food items such as sugar with inferior items such as raw sugar (gurr) during the year 2000.

- There were many instances of postponement of medical treatment due to lack of affordability rose from 33 percent of villages in 1998 to 86 percent in 2000. During the year 2000, 47 percent of the villages reported switching over to herbal medicine which was as low as 9 percent in 1999.

- In terms of purchase of new clothes and foot wear, it was reported to have occurred in 62 percent of the surveyed villages during 1998, which declined to 36 percent in 1999 and dropped to 11 percent during the year 2000.

- Sizeable dropout from educational institutions occurred in the villages surveyed. The main reasons were increased demand for domestic and productive labour and lack of affordability. The cases of dropout because of these two reasons have been reported in 66 percent of the villages during 1999 and 2000. In the year 2000, 71 percent of the dropouts were because of increased labour demand and 29 percent were due to inadequate means of support. Both these conditions were a direct outcome of acute water scarcity during this period.

- There was a sharp decline in 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 further decline in the cropped area and 72 percent reported no crop at all. All the villages reported no annual crop during the year 2000 because of failure of rainfall.

- Reduction/destocking 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.

- Coping strategies were affected. During the year 1999 people in 24 percent of the villages in the study area, took production loans while in the year 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 has occurred in 90 percent of the villages ranging between 5 percent and 54 percent of the total village households. This phenomenon occurred in 80 percent of the villages ranging between 11 percent and 48 percent of the total village households in Mastung. Emigration seriously affected village decision making mechanisms.

- Finally, large scale changes in the primary economic activities: dependence on agriculture as a main source of subsistence has 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 has increased from 7 percent to 32 percent in Qila Saifullah and from 9 percent to 42 percent in Mastung.

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