Spate Irrigation in the Horn of Africa: Status and Potential

2

Overview Paper Spate Irrigation

Spate Irrigation Network

1 Introduction

This report discusses spate irrigation in the Horn of Africa: in Ethiopia, Eritrea, Somalia and Sudan. Spate irrigation is a form of water management that is unique to semi-arid environments, as common also in many parts of the Horn. Spate irrigation can occur particularly where semi-arid mountain catchments border lowlands. Short duration floods come down in the ephemeral streams, lasting from a few hours to several days. These short duration floods are diverted from river beds and spread over land – to cultivate crops, feed drinking water ponds, or irrigate pasture areas or forest land.

When considering spate irrigation, it is important to realise that there are two distinct divisions between the way in which flood flows are utilised in the ephemeral environments. With the older systems that have been practised in arid parts of the world for hundreds or more often thousands of years, the technique has been to apply flood waters to the land and to plant crops, usually sorghum, after the soil moisture reservoir has been filled. More recently, often as a result of the changes in climate that have been most noticeable in the last 20 years, flood flows have been utilised to overcome erratic rainfall, inadequate amounts of rainfall and the impacts of rain shadows. The techniques involved in diverting flood flows for these two situations are different although the principles are similar. This will be discussed later.

Spate irrigation is found in the Middle East, North Africa, West Asia, East Africa and parts of Latin America. In some countries it has a long history - more than 5000 years in Yemen, Pakistan and Iran. In the Horn of Africa spate irrigation is more recent with Eritrea and Sudan having the longest experience and although it is officially recorded as being practised over the last 200 years, it is highly likely that it has been practised on much longer. Particularly in Ethiopia and Eritrea spate irrigation is on the increase.

Spate irrigation differes from other flood-based farming system in that it diverts flood flows from ephemeral streams to enter the irrigation network. The short duration floods on which spate water management is based are often forceful in nature, requiring special techniques and special organizations to manage and distribute the water. Spate irrigation is different for instance from flood recession farming, where the moisture left behind after river flood plains or lake plain are flooded is used[2]. Spate irrigation is also different from inundation canals – where canals flow when water levels in a river reach a certain level. Spate irrigation also differs from semi-perennial irrigation, that uses flows that run for a number of months only[3]. The main difference however

Figure 1 Newly developed spate irrigation system in east harrarghe, Ethiopia.

1) *This Overview Paper is an update of the report Spate Irrigation in Blue Nile Countries, prepared for IWMI.*
2) *Flood plain irrigation is very extensive in Baro Akobo system (Woube 1999) and in the Lower Omo Valley. It also occurs on the banks of Lake Tana in Ethiopia (estimated at 3500 ha).*
3) *Here the distinction is often hazy and the term spate irrigation is also used for semi-perennial irrigation in Ethiopia.*

between perennial, supplementary and spate irrigation is the specific flows that are diverted into the canals[4].

The systems are also categorically different from perennial systems. For one they are risk-prone and exist in condition of large variability. The floods may be abundant in one year and minimal in the next year. The timing and volume varies greatly from year to year and in recent times has been markedly affected by climate change. The fluctuation also brings along an unavoidable degree of inequity, with some lands always better served than others. Spate systems, moreover, have to deal with occasional high floods that – unless properly controlled - can cause damage to river beds and command areas. Another feature that sets spate systems apart from perennial irrigation is the high sediment load of the water. This sediment is a blessing as well as a curse: it brings fertility and makes it possible to build up well-structured soils . On the other hand it can also cause rapid rise of the command area and the sedimentation of canals. Finally, in many spate systems floods come ahead of the cultivation season and storing moisture in the soil profile is as important for crop production as is the diversion of water.

As far as can be established, spate irrigation in the countries in the Horn of Africa has accelerated in the last hundred years, though it is likely that it was practiced by farmers initiative at smaller scale for a much longer period. In Sudan it was introduced at scale during the British colonial government. In Ethiopia and Eritrea this form of resource management has over the last twenty years been increasingly supported by governments and NGOs under national and international programmes. In Somalia different donor programs introduced the systems in predominantly pastoralist areas in in the 1960's and 1970s. Population pressure together with unpredictable rainfall events and amounts in the region is giving a new impetus to this relatively difficult resource management system. In Eritrea developing spate irrigation has become government policy however there are very few professionals within the country with an adequate understanding of the systems to ensure sustainable and cost-effective designs. In Ethiopia new systems are still being developed - with investment of regional government or at the behest of farmers. In Sudan some of the large spate irrigation systems went through a period of decline, mainly related to the collapse of earlier management systems resulting from a failure by government to appreciate the complexity of the systems. However, in the last decade a number of programs are implemented or underway to restore and rehabilitate the systems.

This report takes take stock of the current status of spate irrigation development, summarizes the experiences so far and formulates a number of recommendations on the development of this upcoming resource management system. It first discusses the status and spate irrigation in the four countries – Ethiopia, Eritrea, Sudan and Somalia and then discusses common experience and the potential for spate irrigation in the region. The report concludes with a concise research and development agenda on spate irrigation in these countries.

2 Country experiences

2.1 Spate irrigation development in Ethiopia

Since ten years in Ethiopia spate irrigation is on the increase. Its popularity is part of a larger movement towards higher productivity farming systems - moving away from the exclusively rain-dependent. In almost all cases the development of spate has been in the context of supplementary irrigation. These developments are both linked to the increasing settlement of lowland areas as well as increasing variability and failure of rains in semi-arid areas (<600 mm per annum). These lowland areas for a long time were sparsely populated and utilised by agro pastoralists.
Due to the mounting population pressure in the highlands and progress in controlling tryposonamis and malaria, lowlands are becoming more settled. In some areas spate irrigation is also a response to a trend of perennial rivers to become seasonal rivers - the result of catchment degradation, with flood flows of shorter duration but with much higher peak flows resulting in more flashy floods.
The development of spate irrigation in Ethiopia is driven by both public interest as well as farmers

4) *For perennial and supplementary irrigation unit flows will vary from 0.5 l/s/ha up to in some cases 4 l/s/ha whereas unit flows for spate irrigation can vary from a minimum of 10 l/s/ha up to 150 l/s/ha depending upon the size of both the catchment and command areas.*

5) *It is essential that engineers understand the differences that exist between designing spate and conventional irrigation systems. Not only does the intake have to be significantly "oversized" and related to the anticipated duration of the flood flows, the canal systems have to be designed to maintain flow velocity down the field level with overshot structures and gates avoided.*

initiative. Several regional states, in particular Tigray and Oromiya, have dedicated ample funds for new systems development. Much of spate irrigation development in Ethiopia is very recent though systems near Kobo in Welo and Konso in SNNPR are much older. Yet this is unlike the history of spate irrigation in Yemen, Iran or Pakistan - which stretches over millennia.
The area currently under spate irrigation is estimated at 140,000 ha, but the potential particularly in the lowland plains is much higher (Alemehayu 2008). This is important in Ethiopia, a country that still relies substantially on food aid, to reduce the dependency and to ensure that sufficient food is produced to meet the requirements of a continually growing population with ever declining landholdings and limited access to perennial irrigation. The recent food crisis and the spiralling prices that came with it underlined the situational vulnerability of this. Spate irrigation may also have a role to play in generating surpluses of marketable crops, such as pulses and oilseeds. These are crops that are quite compatible with spate production systems and the often relatively remote locations where the spate systems occur, as they can be both stored and transported to market over very basic road networks.

Ethiopia's annual renewable fresh water resources amount to 122 BCM/yr contained in twelve river basins, which amount to 1525 m^3/yr per capita. At this stage Ethiopia withdraws less than 5% of its fresh water resources for consumptive uses - though undeniably some of the resources/surface streams in the semi - arid parts of the country are overcommitted.

Because of the nature of the terrain in Ethiopia, especially in the East and South, there are hardly any perennial flows in areas below 1500m above sea level and perennial streams and springs exist only in the vicinity of mountains with an annual rainfall of more than 1000mm or near the outflow of lakes. For a long time government-sponsored irrigation development concentrated exclusively on perennial streams that are at times overcommitted, making little use of the potential imbedded in semi-perennial flows and spate irrigation systems. In recent years this has changed and several regional governments have devoted budgets for spate irrigation development.

Some spate systems in Ethiopia have been in use for several generations, but in almost all areas systems have been recently developed. The technology is on the increase in the semi-arid parts of the country: in Tigray (Raja, Waja), Oromia (Bale, Arsi, West and East Haraghe), Dire Dawa Administrative Region, in SNNPR (Konso), Afar and in Amhara (Kobo) region. In southeast Ethiopia the word '*gelcha*' is used - translating as channeling the flood to the farm. In the northern parts the word '*telefa*', meaning 'diversion', is common.

Spate systems are encountered both in the midlands and lowlands in Ethiopia. In Ethiopia a common distinction is between three agro-climatic zones: the (mid)highland (above 1500 meter), the midland (1000-1500 meter) and the lowland (below 1000 meter). At present most spate systems are in the midlands and some in the lowlands. There are distinct differences between midland and lowland systems. First is that in the midlands rainfall is higher and the spate flows complement and are complemented by rainfall. Command areas in the midlands are relatively small, defined by hill dominated topography. Lowland systems on the other hand are larger, receiving water from a large mountain watershed. Lowland soils are alluvial and rivers are less stable. They may degrade, silt up or change course. In long established spate areas in other countries (such as the western bank of the Indus in Pakistan or the Tihama plains in Yemen) farmers have developed traditional techniques (earthen dikes and brushwood deflectors, long guide bunds) that do not confront flood flows but work with the flood flows but breach rather than diverting the very large flows. This management of the systems leads to productive resource management systems - integrating crop production and livestock-based livelihood systems. In Ethiopia at this moment, spate irrigation development in lowland plains is still modest, and often limited to the immediate piedmont areas, where gradients are relatively steep and floods are sometimes more difficult to control than further down the ephemeral rivers.
According to various recent estimates, traditional

Figure 2 Groundwater Exploration, Raja Valley, Ethiopia.

Table 1 Type of spate system in Ethiopia

Spate system	Midland	Lowland
Rain	Supplementary	Less important
Catchments	Limited	Large
Bed material	Stony, armoured	Sandy, fine
Gradients	Steep	Gentle
Flow	Flash floods and semi-perennial flows	Short duration flows with high peaks
Command area	Small	Can be large

spate irrigation in the country exceeds 100,000 ha (Alemehayu 2008). In the Raya Valley alone traditional spate irrigation extends to 21,000 ha (Kidane 2009). Areas under improved or modernized spate irrigation stand at 20,000 ha and considerable investment is lined up: spate projects under design and construction exceed 50,000 hectares (Alemehayu 2008). Most systems are relatively small - with a few systems (Kobo, Yandefero, Dodota) touching the 4000 ha mark.

The traditional systems typically consists of short free intakes - in many cases in a series. In Kobo in Amhara Region floods are diverted from a seasonal river (*Gobu*) and directed to the cultivated fields to supplement the rainfall (Alamerew et al, no date). The main diversion canal is called '*enat mellée*' (i.e. mother *mellée*). The mother *mellée* starts as a small earthen embankment protruding into the flood course at an acute angle with a gradually curving and broadening up that guides the flow to the cultivated fields. These main diversions are constructed at a convenient angle across the riverbed slope to divert the flood runoff and convey it to the command area. The longitudinal slope of the riverbed ranges from 1-3%. The system is further divided into '*awraj mellée*' (secondary canals) and '*tinishua mellée*' (tertiary/field canals). Once the water reaches the field canals, it is spread with the help of bunds and '*shilshalo*' (contour/graded furrows). A special feature in Kobo are the excavated ponds, that serve for livestock watering and are located downstream from the cultivated land. The ponds are fed from the main canal as well as the excess drainage from the cropped area.

Figure 3 Supplementary irrigation from spate, Belilo (East Harrarghe), Ethiopia.

Similarly in Aba' ala in Tigray there are many waterways that run into farms. In total there are twenty-seven primary channels diverted from the three rivers (Haile and Tsegaye, no date). The diversion channels are made by digging an open channel both on the left and right banks of the rivers - strengthened by stone, boulders, shrubs and tree-logs. When there is flood almost all farms get water. Within the farms there are narrow furrows covering the entire field. These furrows distribute and can carry water for some time. The furrows are made in intimate succession to one another and slightly against the contour. Under a Norwegian Aid project some of these traditional intakes have been replaced with masonry walls.

Also the Yandefero system in Konso (SNNPR) consist of a multitude of short flood intakes. At present there are 29 flood intakes - made of soil and brushwood. The entire area that can in principle be irrigated is close to 4000 ha. Eleven of the flood intakes date back thirty years or more. Most of the remaining ones were developed in the last few years under various food for work arrangements. Recently, the Yanda river has started to degrade dramatically - going down one to two meter over large stretches. This degradation most likely was caused by the cutting of a stretch of downstream riverain forest which caused the Yanda river to shift its outlet to a lower section. The degrading of the river bed has forced farmers to extend the flood channels higher up in the river bed - sometime curving around bends. This has left the intake structures more exposed to the force of floods, and several of them are no longer used. The remaining intakes sustain a mixed cropping system of small-holder maize, sorghum and cotton. Farmers do not reside in the lowland area for fear of malaria and tryposomasis. Instead they live in the midlands and travel 15-25 kilometer and stay in Yandafero for a number of days and nights at a time (preferring to sleep in trees or on hill tops) to cultivate land.

Free intakes are the rule in the traditional systems, even in lowland areas. In Western Harrarghe the lowland Weltane system is fed from the Koran Gogoga river through three intakes served by short guide bunds of stones and brushwood. All in all 105 hectares are served owned by some 170 families. As the intakes in Weltane are situated in a gorge it is difficult to control the flood and farmers do not use the peak floods. Instead they use the recession flow only, rebuilding the diversions immediately after the flood. In Hasaliso in Dire Dawa there are a series of free intakes a large part of the flood - some improved under relief projects and some entirely farmer-built, all located immediately downstream of the gorge. The river on this soft alluvial lowland plain is incised and the flood channels are relatively long. Some of the intakes have suffered from changes in the river morphology. As mentioned in comparable lowlands systems in Yemen, Pakistan and Eritrea farmers construct soil bunds that dam up the flow and irrigate both up and downstream area, but such structures are not common in Ethiopian lowland systems.
Until ten years ago much of the external investment in improved spate irrigation systems was done by non-government organizations, but in recent years Water Resources Bureaus in several regions have taken over and sometimes invested substantially in spate irrigation development. The front runner is Oromia State. In Oromia Regional State there are 30 projects at reconnaissance stage, 58 projects under study and design and 38 spate irrigation projects under construction (Alemehayu 2008). The investment program started in 1998 in East and West Hararge Zone, with first systems such as Ija Galma Waqo (Fedis, East Hararge); Ija Malabe (Fedis, East Hararge). Bililo (Mi'eso, West Harargee) and Hargetii (Mi'eso, West Harargee). These systems concern both semi-perennial and spate irrigation systems. One of the largest systems is Dodota, situated in a rain-shadow area in Arsi. Dodota takes its water from the semi-perennial Boru river (van den Ham 2008). The stream has no other off-takes upstream along and is not used by other upstream or downstream users. The total net potential area for spate irrigation was estimated to be approximately 5000ha. The main objective of the design was to supplement the rainfall in the area. Based on the requirements, permanent diversion structures were made with concrete and masonry. A striking feature of the design process

Figure 4 Improved small spate irrigation system, Ija Galma Wago (East Harrarghe), Ethiopia.

was "parallel implementation", as the design process was continuing parallel to the construction. A digital evaluation model was used and design were prepared and adjusted as the project was implemented.

Other states have also launched spate irrigation programs. In Tigray the regional government in the last ten years has made efforts to improve the traditional spate irrigation systems particularly in the Raya Valley. The current ambitious plans for the state aim to increase the entire area under irrigation from perennial sources, micro-dams, groundwater and spate flows. The Water Resources Bureau has implemented more than thirteen modern spate irrigation schemes sized between 250-500ha. Similarly in Afar spate irrigation development is on the way in for instance. The Tali and Alena irrigation projects were built in 2007/2008 to utilize the emphemeral flow from the Tali and Gulina respectively.

The development cost of spate irrigation projects varies from place to place. In remote area labour costs are low and locally available material may be used, but the cost of mobilization and demobilization of machinery make the projects expensive. The scale of projects also affects the cost. In modernized structures with civil works the community input is often modest (not more than 10%) and as a result the project cost is high. On the other hand the local contribution in improved traditional spate irrigation systems is very high and this reduces public investments. According to estimates from ongoing spate projects, the current construction cost of spate projects ranges from USD 170 to 220 per hectare for non permanent headwork, including soil bunds, gabion structures and diversion canals and up to USD 450 for permanent headwork for small systems including diversion weirs and bunds (yet excluding protection or guide bunds). The cost of permanent headwork for large systems including diversion weirs breaching bunds and siphons as estimated form on of the ongoing project (Koloba Spate Project) ranges from USD 330 to 450 per hectare (Alemehayu 2008). Work is usually implemented by government directly. These costs are very reasonable and at par with 'sensible' investments in spate irrigation elsewhere (van Steenbergen et al, forthcoming).

Experiences

Comprehensive data on crop yields and other benefits from spate irrigation developments are still unavailable in Ethiopia. The modest evidence that exists suggests that yields are a big leap up from rainfed farming. It must be borne in mind that most spate irrigation developments in Ethiopia are effectively supplementary irrigation. Such developments have taken place in areas where rainfall has become or is increasingly unreliable and therefore any increase in water application will have a direct impact on crop yield when compared with adjacent agricultural areas. The key issue here is to encourage such relatively small investments in spate irrigation as in years with more variable and lower levels of rainfall, these investments will make the difference between no significant crop yield and a recent crop yield. In an average year, yields can be double or treble the rain fed yields. The most comprehensive assessment was done in Dodota, a rain shadow area in Asella on the Leeward side of the Asella Mountain. The Dodota system received regular spate supplies for a four month period and is almost semi-perennial. A comparison of yield data for the irrigated and non-irrigated area shows that for all major crops, the increase in yields was substantial. Wheat yield went up from 4 to 13 ton/ha; barley from 7 to 26 ton/ha; teff from 3 to 6 ton/ha and haricot bean from 6 to 15 ton/ha. The most spectacular increase from rainfed to spate-irrigated was for maize: from 8 to 32 ton/ha (van den Ham, 2008).

One feature in many of the midlands systems is the large variety of crops. In Eja Gelma Wako in Fedis in East Harrarghe, where the rain-fed crops received supplementary flood water supplies, the cropping pattern included sorghum, maize, groundnut, sweet potato, pepper, onion, garlic, local spices and medicinal plants, but also mango and qat (*chat cadulis*). The qat is entirely spate irrigated - springing to a new harvest of fresh leaves after a spate irrigation. To survive the dry period leaves are removed by hand from the chat so as to reduce evapotranspiration from the plants.

The variety of crops in lowland systems that depend typically entirely on the flood flows is less - with more reliance on annual staple crops such as sorghum, maize and sweet potato. It appears that some of the lowland cash crops common in lowland spate irrigation systems elsewhere in the world, such as pulses (mung, chickpeas, clusterbeans) and oilseeds (castor, mustard, sesame, rapeseed), have not made inroads in lowland systems in Ethiopia, even though they would fit in well with the often remote locations of the spate irrigation areas.

There is considerable investment in 'modernized' spate irrigation systems, as described above. In the completed systems however operational problems are galore. Many of the modernized systems use designs that are akin to perennial irrigation systems. In many cases a typical design consists of a diversion weir with an undersluice and a gated intake. There is often little adaptation to local circumstances and making use of the engagement of farmers in the design process. While many systems still need to come on-stream, many of the problems which such conventional approaches in other countries are also prevalent in Ethiopia (Lawrence and van Steenbergen, 2004). An extensive study on 50 'modernized' spate irrigation systems in Balochistan found exactly the same problem - with less than 30% of the improved schemes being functional ten years after completion (van Steenbergen 1997). This is part of a larger problem with modernized or improved spate irrigation systems globally: the failure of designers to look at all aspects needed for the spate development - and in particular limited practical experience on designing river training structures and conveyance systems or inadequate appreciation for the importance of on farm water management or farmers solutions in general.

A review of the spate irrigation systems in Aba'ala in Tigray Haile et al (nd) lists the following problems with the improved systems:

- Upstream and downstream users do not share the flood flowing through the iver equitably;
- Technical faults in developing local diversion canals triggering changes in the river course;
- Improper secondary and tertiary canals leading to in-field scour and creation of gullies in the fields - which educes available soil moisture;
- Large amount of sand deposition in the canals and even in the cropped fields;
- The large maintenance burden of traditional spate irrigation systems.

In Aba'ala the traditional intakes - with a

Figure 5 Capturing the recession flow, Weltane (West Harrarge), Ethiopia.

typically very high maintenance burden - were in several instances replaced with stone masonry walls that were supposed to relieve farmers of these time-consuming tasks. These walls were not able to stand up to the floods and in several cases were toppled over. Along the Murga river this also led for instance on the Murga river, to the abandoning of previously cultivated land.

An evaluation of a number of other improved systems in Tigray came up with similar points (Teka et al, 2004). The Tirke irrigation system for instance suffered from the blockage of under sluices/off-takes by boulders, sediments and trash and erosion of downstream protection works as inequities in water delivery between land owners in the command area. In the Fokissa system similarly sedimentation was an important issue - manifest in the silting up and blockage of pipe inlets and sluice piers that catch trash and boulders during floods. In the Tali system in Afar too sedimentation was also main problem as well as the lack of preparation of field plots. Similarly the Belilo system in East Harrarghe suffered from heavy sedimentation.

The Hara system in Tigray even failed entirely by relying on non-appropriate perennial irrigation design concepts. Prior to its modernization farmers along both banks of the river were using spate water from the river using traditional diversion structures. This was replaced by 35m length concrete masonry weirs. The modern headwork was build to supply spate water for commands at the right and left banks of the river. At both ends of the weir 32 inch diameter pipe intakes were constructed at right angles with the rivers as well under sluices to remove the sediment in front of gate facing parallel to the river. Both the intakes and the under sluice gates were provides with gates operated with winches. The primary and secondary canals, which replaced the traditional ones, were made of combination of earth and cement masonry. The canals are earthen structures lined with selected material and the drop structures, crossing and sedimentation ponds are made of cement masonry structures. The spate system started functioning in 2003 but failed the next year. The main reason was that both gated takeoffs of the weir were silted with a huge amount of sand and boulders after each spate flow - and this became too difficult too clear and rehabilitate by the farmers (Kidane 2009).
Other 'modernized' systems suffered because they were not able to adequately cope with sedimentation and trash deposits. The trash accumulation problem was at its most spectacular in Ondoloko in SSNPR. At this site, a gabion weir and gated offtake channel were constructed on a small steep sand bed river. The diversion was not well sited, i.e. on a very sharp river bend, so virtually all the river flow was directed towards the canal intake. As a result the structure collected an enormous amount of flotsam and ceased to be operational.
There are a number of common issues related to these design and operational problems. Spate irrigation is categorically different from conventional irrigation. The first problem relates to design and engineering issues. The most important aspect is that intake and canal design must comprehend the high variation in flow that takes place in the source river over a relatively short time. This means that the time of exposure of the intake to water is much more limited than in a conventional irrigation scheme. Maintaining velocity in these circumstances is essential so that once water has entered the canal, as far as possible, relatively high velocities are maintained to ensure that the high volume of sediment that enters at the intake remains in suspension until it reaches the field. The next most important design aspect is to ensure that no obstruction is provided to the flow that will encourage low velocities and hence high sediment deposits and the trappings of the considerable trash loads that occur in the rivers during floods. Proportional dividers with angled intakes have proven to be the most effective designs. Experience all around the world is that weirs with high crests that encourage local reductions in velocity particularly during the recession limb of the hydrograph quickly silt up and that the standard solutions, such as sedimentation basins and scour sluices do not work, mainly due to the wide range of grading of the materials transported by the very high velocity state floods. Sedimentation basins generally do not work because the conventional designs rely upon a much narrower range of transported sediment. In the spate rivers much coarser material is transported from

dry unprotected and eroded catchments as well as material picked up from the dry granular riverbed. If these materials enter the sediment basin, the resultant velocity change results in the debt position of an enormous amount of coarser materials. These are also mixed with the finer materials and therefore hydraulic flushing is difficult and probably ineffective and mechanical cleaning can only be achieved by excavators working from the bank of the sediment basin. The cost of the latter is far beyond the reach of farmers organisations and the use is questionable as the basins will fill up after every flood. Flushing excess sediment from sedimentation basins under these conditions can only be achieved with large amounts of water in areas where water is very scarce and farmers want to make as much use of it as possible as they do not know when the next flood will come. For the same reason sluice gates are often kept locked or blocked.

The function of modern weirs in spate irrigation systems is to provide a stable section that is not subjected to head cutting and hence varying riverbed levels. Designs for modernisation and therefore need to comprehend this and a practical solution is the creation of river bed "bars" that provide no obstruction to the wadi/floods flow but maintain the location of the offtake to the canal system. The problem of creating "head" to ensure that water enters the canal system occurs in some cases but provided that the principle of minimum obstruction to spate flow and maintenance of riverbed level are adopted, these can be accommodated in most cases provided that suitable sites are available. The combination of bed bars, proportional intakes and simple traditional diversion structures - from stones, sand or brushwood - have proven effective in locations where no obvious diversion site exists. All works must consider the need for cost effective and appropriate river training and guiding in combination with the control structure and intake. Experience has shown that traditional means for reinforcing the exposed "node" of the weir and guide structures using large stones and/or gabions formed in a conical shaped structure are effective in reducing damage to the guide banks and subsequent costly and difficult rebuilding. Such structures still require the same attention to depth of foundation and scour to ensure that they are well anchored in the river bed and not subjected to undermining and rotational failure. High variation in flood levels characterize spate irrigation. It is essential that high flood levels even of short duration are not allowed to enter the canal system. These can be excluded using breach sections in the guide canal for the intake and orifice control at the intake to ensure that only flows that can be contained within the downstream canal pass through the intake. Breach sections are common in traditional structures that are washed out in high floods and by doing so serve to keep the erosive high floods with very high and coarse sediment loads out of the command area. Gated intakes are generally avoided in spate systems as unless they are electrically or hydraulically operated cannot be closed in time to exclude high flood flows that occur in a very short periods, in some cases under 10 minutes. They also require attentive gate operators as many spate floods occur at night time or in the early hours of the morning.

The second problem is organizational. In many of the new spate irrigation systems that apply supplementary water to traditional rain fed areas, access to water and loss of land are major issues that if in your before the start of investments will create conflicts and major operational problems. As with perennial irrigation systems, the need to establish agreement on land and water rights before implementation is essential. An example of the type of conflict that can occur is on the Weida river in Konso in Southern Ethiopia where more than 200 persons were killed over a water dispute between investors and pastoralists. It is important to understand that such water rights are different from the sharing and allocation of perennial flows. The water rules in spate rivers are more reactive - responding to a situation that differs from year to year as well as within a year. The water rules concern more 'agreed principles' on water use: agreed priories of sharing when flows are scare; the area entitled to irrigation; the location of the diversion structures; rules on breaking them to allow water to pass on downstream; rules on protecting river banks and not allowing floods to

Figure 6 Old and young water master. With improvement of the system a new water master was selected, Belilo (East Harrarge), Ethiopia.

escape to another area (Haile et al. 2007). As spate irrigation expands in Ethiopia, the need to work proactively on such water rules increases. It is also particularly important to respect and incorporate the rights and established practices of pastoralist groups and other downstream users. A certain degree of inequity between upstream and downstream users - between and within systems - is inevitable, but improvements under modernisation should reduce such inequalities instead of enhancing the strength of upstream users. Some measures can mitigate this. One is the make sure the command area is not too overstretched. A smaller command area will make it more likely for farmers to have two or more floods, which can highly increase productivity as crops are no longer in the 'stress zone'. In a larger area, zoned systems are important, reducing the overall command area into manageable blocks. In such systems it is possible to have the upstream area served by a modernised weir and distribution system and the downstream area depending upon traditional local diversion bunds and abstraction techniques, all governed by common water rights.

Apart from water rights, the capacity to operate and maintain is very important and can not to be taken for granted. Spate irrigation systems are based on traditional practices and thus designs and O&M requirements must reflect the same level of technology and local capacity. Peer policing of water use (using the "water master" system) is essential to ensure equity of supply. From Raja and Kobo there are anecdotes of farmers blocking floods with their bodies to divert the water to their fields. Spate irrigation thus not only requires vigilance to catch floods but also and substantial community cohesion and shared work to keep the system intact, to remove the sediment and ensure a adequate and acceptable sharing of resources. For this reason it is important that farmers are involved in all steps of the development of new systems and that designers

Box 1 Farmers organization in spate irrigation in Raja Valley, Ethiopia (Kidane 2009)

In the traditional spate systems in the Raja Valley farmers elect *Abo-Gerebs* ('fathers of the river' or water committee members) and *Abo-Mais* ('water masters'. i.e. secondary group leaders) with no external intervention. These local functionaries are elected for an unlimited period of time. A members of Water Committee or *Abo-Mai* can be replaced by another mainly if he wants to resign for private reasons or if other water users want him to be replaced. Criteria for election are personal integrity, social acceptability and fairness in administration. The members of *Abo-Gerb* or *Abo-Mai* do not receive any kind of payment for their service in the spate irrigation system. The main functions of the *Abo-Gereb* and *Abo-Mai* are scheduling water distribution, coordinate the maintenance of infrastructures, resolving conflicts, enforcing regulatory procedures and punish offenders. The *Abo-Gereb* and *Abo-Mai* are also vested with the power of water allocation to each secondary channel, and prevent water theft.

Responsibility of the *Abo-Gereb* (Water Committee):

- Organize O&M works before the arrival of the rainy season;
- Organize meetings and perform lottery draws on the irrigation sequence of the secondary cannels for the coming rainy season;
- During spate occurrence decide how many secondary canals can be supplied with spate water at the same time;
- Supervise the distribution of water to the secondary canals and verify and register the level of satisfaction with in each group;
- Facilitate the opening and closing of canals according to the established sequence spate irrigation;
- Monitor the diversion weir and the irrigation channel during irrigation and organize emergency O&M activities during the rainy season if necessary;
- Implement the *Sirit* (rules and regulations of the spate system).

Responsibility of the *Abo-Mai* (Leader of Secondary Group):

- Represents his group (called '*gujile*') in the overall committee;
- Organize his group members for construction and maintenance of the spate irrigation infrastructures of the system;
- Supervise the distribution of spate water with in the group and settle any problem arising;
- Implement the *Sirit* (water rules) with in the group - for instance impose fines on those who violated the Sirit and who do not participate in the operation and maintenance works;
- Report out of hand problems that arise within the group to the overall committee.

and farmers understand the need to respect traditional systems where they exist to ensure that they are made an integral part of the design process.

This raises a final main issue that relates to field water management where substantial gains can be made. There are type types of approaches to the use of the soil moisture reservoir depending on whether the land is pre irrigated or applied after the crop has developed under rainfed conditions. For traditional spate systems where floods arrive before the growth season, storing moisture is as important as diverting floods. This is achieved by ensuring that bunds are high enough to ensure maximum storage is achieved particularly when infiltration rates are much lower than application rates. New systems such as Gulina are most vulnerable as many rainfed farmers do not understand the means for filling of the soil moisture reservoir using applied spate water. In this sytem, field bunds were not well prepared and an insufficient proportion of the applied water was retained. In Dodota the increases in crop yield could have been even larger - with better field water management. At present pre-irrigation land preparation (allowing better infiltration of the flood water), deep ploughing and mulching (to conserve moisture) are not practiced in Dodota. A main reason is the shortage of draught animals and the general weakness of them. Investments in infrastructure may be complemented by programs to ensure a better stock of draught animals.

2.2 Spate Irrigation in Eritrea

Historical spate Irrigation in Eritrea has not well documented. Although many developments are a relatively new phenomenon, examination of the depth of soils, terminology in use by the farmers and the organisation that has developed in the Red Sea (Eastern Lowlands) area would indicate a much longer history more associated with those in Yemen that those in Southern Eritrea (Western Lowlands - Gash Barka and Zoba Afabet). The area presently under spate irrigation (assessed at 14,000 ha) is a fraction of the area that could be developed (estimated by various sources between 60,000 to 90,000 ha). As in other sub-Saharan Africa, the area under spate irrigation is increasing in response to the increasing variability of rainfall and the extended periods between rainfall events. A large number of threes initiatives are farmer instigated but these have been further developed under Donor and NGO support.

Different from Ethiopia, spate irrigation in Eritrea mainly takes place in lowland regions where some systems are relatively large in area of coverage (> 500 ha). Two distinct types of spate irrigation are practised in Eritrea. In the Northern Red Sea areas, traditional spate irrigation is practised with plots flooded prior to planting. In the southern areas, post planting spate irrigation takes place with most systems acting as supplementary irrigation schemes.

Traditional spate systems in Eritrea are found primarily in the Eastern Lowlands and in the coastal regions. The traditional systems rely heavily on sand, stone and brushwood spurs and earthen guide bunds. The brushwood used is often Acacia, with its characteristic fine needles providing a solidly interlocking bund. This helps to trap other sediment and floating material. This protects and reinforces the rather loose and sandy guide bunds in many of the lowland areas. The heavy demand for acacia branches has depleted some areas of these tree stands - making it more and more difficult to collect the material. Spate irrigation in these areas is more sustainable where longitudinal slopes of the Wadi bed do not exceed about one in 100 (e.g. Wadi Laba). In these locations, stone boulders and can be used to construct temporary bunds are not generally found which puts greater pressure upon available trees and scrubs.

An example of a traditional lowland system is Bada (gross command area 2,000 ha). It is located in one of the most hostile environment of the world, at minus 115 meter below sea level, the Danklyl depression - practically on the Eastern border with Ethiopia[6]. The climate in Badas is semi-desert and hot. The coolest periods have average maximum temperatures ranging from 20 to 30 degrees Celsius, but in July and August temperatures easily soar to 50 degrees Celsius, exacerbated by strong dry winds, that cause soil erosion and reduce soil moisture. The source of water for the Bada is the Regali River. The floods originate from the high catchments of Adi-Keih (Eritrea), Adigrat and Edaga Hammus in Tigray (Ethiopia). As in other spate irrigation areas the predominant soils of the plains are alluvial silts, which originating from the heavy sediment loads that the spate flows bring. In Bada one flooding can accumulate 5-7 cm silt on the field (Haile and van Steenbergen 2006).
Several indigenous engineering techniques

6) According to some sources maintenance work on the spate systems on both sides of the border is coordinated.

have been developed in the older systems to divert and use the temporary flows - not unlike traditional spate systems in Ethiopia or Yemen for instance. Two types of diversion structures (*agim*) are common in Bada: deflector type low earthen bunds and weir type low earthen bunds. Deflectors extend into the bed of the wadi at an angle to the direction of flow and are protected by brushwood and stones. In Bada they are of relatively short length, i.e. 20-40 meter. If the flood is very high and beyond the capacity of the off take, the structure will be breached with flood flows passing down the Wadi to the next intake. This serves not only as a safety valve sparing farmers the destruction of canals and field embankments, it also ensures more equitable water use down the Wadi. The weir type of *agim* on the other hand is constructed at more or less at right angles to the wadi banks and extends over its full width. In this system, the diversion structure is built from riverbed material extending across the low flow channel of the wadi with the objective of diverting the entire low stage of the spate flow to their fields. As there is no provision for a spillway, this type of *agim* - as with the deflector type - is either breached deliberately or it is overtopped and breaches by itself during a large spate flows. Different *agims* have different characteristics. Farmers in Bada assess soil *agim* as having minimum seepage, but being relatively easily washed away by floods. Stone *agim* resist better the force of floods but cannot retain water. An *agim* constructed of brushwood and tree trunks neither resists the force of the flood, nor retains the water but if well constructed can divert sufficient water for the off take and ensure even base flows continue down the Wadi. Gabion *agims* are more durable if well designed but are relatively costly to build and the material and skills are sometimes difficult to obtain.

In a good year Bada irrigates almost all of the gross command area of 2000 ha. Much depends on the size of the floods, interval between flood events and total number of useful floods per season. If it is possible to carry out repairs in between flood events, a relatively good harvest can be obtained. Water is channelled by the diversion structures through intake structures (either designed as orifices all throttling devices) through a network of channels to the command area. Traditionally in, water is provided proportionally to the channels by continuous flow with overshot structures avoided. The field structures are developed in such a way that they can deal with the sudden release of water and avoid scouring and gullying and make sure that in-field erosion is minimized (see also box 2). Another important area in the Eritrean Eastern Lowlands with a history of spate irrigation is the She'eb region - including three important lowland systems: Wadi Laba, Mai Ule and Wadi Labka. In this area traditionally flood water - emerging from different gorges - was diverted by acacia brushwood spurs. In the case of Wadi Labka, the force of flood flows is too large as it enters the floodplain and the practice for these systems was to first split the flows into two usually in the ratio of 1 to 2 or 1 to 3 using a traditional flow splitter constructed from stone and forming a type of round pointed arrow that presents minimum hindrance to the flow. The brushwood weir would then be placed across the channel with a smaller flow and work in a similar manner to those of the Wadi Laba or Mai Ule. In the course of a normal flood season the diversion structures had to be rebuilt 5 to 6 times, with substantial effort.
One aspect of traditional spate irrigation development is the attention given to operation and maintenance of the systems, something that is often lacking in the newer systems. The approach is very practical and has been developed over a considerable time. The articulate indigenous organization is similar to those developed for the systems in Ethiopia (see box 1). Farmers are organized into groups (*parta*) and sub-groups (*teshkil*). A *teshkil* normally consists of 20 to 40 farmers. The *teshkil* leader organizes water distribution and maintenance works within his area and is the go-between between the individual farmers in his sub-group and the group leader or *ternafi*. The *teshkil* also mobilizes and supervises a team of farmers to work on main structures; oversees the water distribution; reports conflicts; and conveys requests from individual farmers to the *ternafi*.

Most partas have more than one leader but one is usually a primus inter pares. This ternafi is expected to assess labour requirements for common works and convey information and

Figure 7 Acacia brushwood used for diversion and guide bunds: source of deforestation, She'eb, Eritrea.

Box 2 Flood channel network structures in Bada, Eritrea

Distributary canals
These are generally permanent canals that convey water from the intake to the different zones of the spate irrigation scheme. Generally they have been sized to accommodate the maximum flood flow that can enter the intake and will deliver this flow proportionally between the lower level order channels.

Field channels (*Bajur*)
The *bajur* is the channel leading water to the fields within a particular zone. The word is also used for the subsections (zones) in the command area. The purpose of the field channel is to deliver water to the agricultural lands in quantities proportional to the irrigated areas independent of the size of the flood in the wadi. Where distributary canals do not exist and water is delivered traditionally from field-to-field, the *bajur* conveys water directly from the diversion structure or *agim* to the first fields.

Spillway *(Khala)*
These *khala* control the amount of water entering the fields. The structure is constructed on the side of the embankments of the field canals. The crest length of the spillways varies between 1.2 and 3.5 m with a free board that varies between 40 and 75 cm. They act as side or lateral spillways discharging flows that exceed the capacity of the field canals (*bajur*) back into the main canal. *Khala* are usually built on the earth embankments of the *bajur*. The crest of the khala is covered by grass or riprap to control erosion.

Drop structure (*Mefjar*)
Mefjar structures are built in spate canals either when a canal has a steep longitudinal gradient; when water is transferred from a higher canal to a lower one; or when water is diverted from one field to another. The purpose is to dissipate flow energy to minimize scouring. The structures are usually made from interlocked stones with gaps filled with smaller stones. In some cases the drop structure is covered only by grass. The width of these drop structures varies according to the size of the canals; the height typically varies between 40 to 60 cm.

Soil retention structures (*Weshae*)
These structures are built on the edge of the wadi to protect the agricultural lands adjacent to the wadi from stream bank erosion. They also serve as silt collectors by creating areas where flow velocities are low and where silt is thus deposited. In time, these plots contain sufficient depth of deposted material that can be used for the development of new lands. *Weshae* are usually built in a similar manner to the *Mefjar* interlocking stones and gaps filled with smaller stones. Stones used in construction are usually laid in one plane parallel or at a slight angle to the direction of wadi flow to minimise the tangential flood force on the structure. This type of structure is also used to create guide walls to control large floods at the approach to the diversion structure or *agim*. In this situation the structure is constructed at least 10 m upstream from the diversion structure or *agim*. The size of the structure depends on the geographic position of the site.

instructions from the administration to the sub-group leaders in his area of influence. The ternafi for instance will investigate a farmer who has failed to provide agreed contributed labour and determine the penalties due. He also transfers requests to the local administration and organizes the distribution of agri-inputs on behalf of the government. Decisions relating to the whole system are made by the group leaders together who form a Spate system committee. This committee has responsibilities that include planning the design and location of diversion structures, allocating and distributing water between the main groups and deciding on the timing and extent of the planting season.
Water distribution in She'eb is primarily from field-to-field. There are only a limited number of field channels. Under the field-to-field system water is impounded in one field to an agreed level before it is guided to the next one by breaking one of the field bunds. The existing rules for She'eb give priority to land that was not served during the previous irrigation period or season and where possible gives higher priority to irrigated downstream land. In practice this means that early in the flood season larger floods are directed to the tails of the *partas*, a practice called *bajur*. Smaller flood flows unable to reach further than the land closets to the Wadi, generally end up in the head reaches of the system. In a good year a field may receive 3-5 pre-planting irrigations.

Traditional systems show a high level of water management. However, a critical factor is the availability of draught animals to prepare the land (ploughing and mulching) and to create the larger agims. It has been estimated that farmers having their own oxen can increase crop yields by 30 to 50%, because they can plough and mulch more frequently.
The irrigation season by and large ends in September, after which the cultivation season starts. Once the main crop has emerged, farmers are hesitant to apply further floodwater onto the land, in case it damages the young plants. Similarly, later in the growing season when the crop stands are higher, there is the fear that additional irrigation would invite pests and prolong the growing season and thus floods occurring post-September may be diverted to other areas.

The major crop in She'eb is sorghum. When floods are late or erratic, maize and pearl millet are grown. The most popular sorghum variety used to

Figure 8 Traditional maintenance of diversion and guide bunds, She'eb, Eritrea.

be *hijeri*, which has a good taste, but has become increasingly vulnerable to pests and diseases. In recent years the *Tetron* variety introduced from Sudan has gained popularity and became the dominant variety. As in other spate systems, there is a strong linkage between agriculture and livestock keeping - the local perception of a rich person is one that has both irrigated land and livestock. Having one's own drought animals makes it possible to plough and level the land soon after it has been flood-irrigated - and so conserve precious soil moisture for the growing season, which starts in September only. Farmers are aware of the importance of soil moisture conservation in spate irrigated areas and with timely land management it is estimates that this translates into harvests with 30 to 40% higher yields.

Investment

As noted earlier, investments in spate irrigation in Eritrea have taken place in the Eastern and Western Lowlands where a large number of relatively small systems have been developed in the area commanded by the Gash and Barka rivers. Development costs for state irrigation in general should be in the order of USD 500 - USD 1500 per hectare commanded. For systems such as Bada where new headworks and other improvements have been built, higher investments can be considered viable. This should be compared with the breakeven limit of USD 5000 considered for perennial irrigation schemes. However, any structures developed within the wadi river courses must be based on good estimates of flood flows and conservative considerations of depth of scour. In the case of Bada where gabions were used to replace the traditional way, it would appear that sufficiently rigorous designs were not developed as this structure only lasted a few years following a damaging flood event). The need for good designs based on improvement to existing traditional developments together with reasonable hydrological estimates is illustrated by the Naro spate irrigation system. This has been under preparation for some time but has not been implemented due to problems of sedimentation. The first attempts at the development of Naro were not successful and this could be attributed to the fact that it is a 'virgin' scheme; there is no history of spate development in the particular area and very little agricultural settlement.

In two of the She'eb systems - Wadi Laba and Mai Ule - substantial investment was made in late 1990's and early 2000's under the IFAD-funded Eastern Lowlands Wadi Development Project (ELWDP). This undertook modernization of the traditional systems at a cost of between USD 2,500 to USD 4,000 per hectare. The approach drew heavily on the earlier experiences of similar modernization projects in Yemen (Wadi Mahr; Wadi Rima; Wadi Zabid) with comparable elements and investments. These included modern permanent headworks structures equipped with off-take gates, weir, breaching bund, scour sluice and sedimentation basin. To reduce the size and costs in the headworks structure, a breaching bund (or fuse plug) was a special feature in the Wadi Laba and Mai Ule designs. This fuse plug comprises an earthen bund adjacent to the main diversion structure was designed to breach during floods that exceeded the predicted 1 in 100 year flood used to design the permanent weir (excluding freeboard). This enabled a smaller permanent structure to be built and also ensured the protection of the main weir body from damage during large flood flows. Although the concept proved valid, the reinstatement of the breaching bund was difficult considering the river bed conditions after large floods and the capacity of the intake structure had not taken sufficient notice of the nature of the flood hydrographs for larger and very large flood flows. In addition to development of the headworks, command area improvements are identified. These consisted of improvements to traditional off-take channels (required to connect with the new headworks) and the provision of permanent cross regulators and off-take structures. The command area developments proved to be more to the farmer's liking as they had been undertaken in full and regular consultation with the farmers and based on the traditional design concepts of proportional flow division.

In preparing the designs for the systems a number of constraints existed. The first and most important consideration was that the preparation of the detailed designs had interrupted three times by hostilities between Ethiopia and Eritrea. This had affected the continuity of both the consultants design staff and also most importantly, the counterpart engineering staff that changed every year for five years. In addition to this, there was (i) a complete lack of hydrological data, (ii) an incomplete understanding of the spate systems and (iii) a lack of compatibility between cost effective designs and farmers priorities. Although hydrological data were collected for two years at both sites, it was only at Wadi Laba, a long and relatively narrow catchment extending into three agro-ecological zones, was compiled carefully considering that base data for only two years were available. that a proper correlation was developed using the data collected with model data. For Wadi Mai Ule, the hydrological results from Wadi Laba were applied directly to Wadi Mai Ule, a catchment covering only one hydrological zone and being much more compact shape, as pressure was mounting from government to implement this project without further delay. Because of the pressure to accept incomplete hydrological data, most important data on the shape of the flood paragraph and the time to peak were not obtained. This impacted negatively on the design of the breaching bund that in the farmer's opinion broke too soon thereby reducing the exposure time of the new intakes to flood flows. It also confirmed the farmers concerns relating to the locations and designs of the intakes on both schemes that in their opinion did not meet what was required to replicate the traditional water management practices - engineers were concerned with reducing the size of the headworks, limiting the amount of silt entering the systems and confining irrigation to a command area that would in their opinion provide a balance between size of headworks and intake (and hence area irrigated) and cost.

This came to a head 2002, the first year of full operation, when floods in excess of a one in 250 return period occurred in both catchments causing substantial damage to river training works on both state irrigation schemes The analysis indicated that at Wadi Laba the breaching bund broke too late and that at Wadi Mai Ule, the downstream change of Wadi course that was part of the improvement works was too rapid (~ 90°), to place too close to the Wadi gorge and that the capacity of the new Wadi channel insufficient and inconsistent therefore causing a throttling effect at large flows and creating a backwater that over topped the guide banks causing the flood flows to pass through the irrigation scheme. It was concluded that the construction of such

Figure 9 Modernized headworks at Wadi Laba: weir, intake gate, sluice gate, sedimentaton pond (not visible) and breaching bund, She'eb, Eritrea.

Figure 10 River engineering approach at work: deflectors and protection bund improved with gabions and earthwork, Wadi Labka, Eritrea.

structures in locations where the Wadi is emerging from narrow gorges into the colluvial fan was questionable particularly considering the limited information available on the flood paragraphs - in traditional systems comparable soil bunds (for instance in Bada) are usually found much further down the colluvial fan. When intake capacity for spate irrigation systems under similar conditions in Yemen is examined (10 to 40 l/sec/ha) it can be seen that these systems with a design duty of less than 5 l/sec/ha were inadequate. Ironically, if the intakes had been designed utilising wider experience, it is likely that the impact of the very high floods experienced in 2002 would have been reduced to some extent.

Two other problems were experienced with the modernized design in the She'eb systems. The first related to the sedimentation basin in Wadi Laba that was designed to trap coarser gravel material but in practice accumulated both coarse and fine sediment. This meant that it impossible to clean out the sediment basin after each flood is intended in the design: too much material to remove and practically it was not possible for bulldozer to operate in the wet fine sediment. The second problem related to a siphon intake beneath the Wadi from the sediment basin to take water from the left bank of the river to the right bank. This intake had both insufficient capacity and was unable to operate as designed due to a problem with the levels that caused accumulation of sediment in the siphon barrels and discharges less than the designed discharge. The other problem was the location of the siphon intake. This was at right angles to the direction of flow, and this combined with the relative short duration of flood flows and the limited intake capacity meant that sufficient water for the command area could not be obtained. Annex 1 presents a detailed description of the works.

After the exceptional August 2002 flood a successful accelerated effort was made to restore the flood damage to ensure that the opportunities for the next state seasons would not be lost as well. The subsequent year was, particularly in Wadi Laba, a 'good' year with 28 floods up to the end of the flood season and 13 more in September-December. Similarly 2004 and 2005 were good years in Wadi Laba with 15 floods in 2004 (mainly medium and large floods) and 39 floods in 2005. In all these three years, the area under cultivation was around 80% of the total commanded area in Wadi Laba. In Mai Ule - the other modernized She'eb system - coverage was considerably less (20-30%) in 2003 and 2004, but in 2005 it also touched 80%.

These seasons made it possible to review the

Figure 11 She'eb Farmers Association, collecting equivalent of USD 40/ hectare for maintenance - among others, Eritrea.

operation of the system under actual flood conditions. One major issue has been that the breaching bunds were breaking far more frequently than the once in five years that was anticipated. This relates to the shape of the flood hydrograph and the time to peak. Once the breaching band has failed, it is not possible to get the designed discharge into the main irrigation intake on either scheme. The breaching bund in Wadi Laba broke once in 2004 and once in 2005. The Mai Ule bund failed 2-3 times every year, in this case effectively loosing half of the medium and large floods in the wadi. In Mai Ule the frequent breaching is related to the rapid rise to peak flood level which takes only 5 to 10 minutes. This very short exposure time of the flood combined with the relatively small size of the intake meant that it was impossible to obtain the required volume of flood water through the intake. In both systems it was difficult to repair the breaching bunds in time - and bulldozers had to operate from the downstream part of the river bed where the material for restoring the bund is more coarse and not ideal.

Farmers compensated for some of these shortcomings by making their own non-engineered but practical adjustments to the system. In Wadi Laba, a hybrid modern-traditional system developed with flood flows that passed down the through the breached bund being diverted by a traditional agim downstream to serve part of the same area supplied by the main intake at the head works prior to breaching. At Wadi Mai Ule the adjustments were significant with the realigned Wadi course being closed and replaced by a new intake and earthen diversion bunds that closely resembled the traditional systems that existed before the rehabilitated works were constructed. Much of the adjustment work was initiated by the formal water users association that was established in 2004 (following the bad floods of 2002). The structure of this 'She'eb Farmers Association' (SFA), established under the ELWDP project, was modelled on the traditional leadership of ternafi and teshkils described above. To this traditional structure the SFA added a superstructure, i.e. an Executive Committee that was taking charge of the management of the entire She'eb Spate System, both in Wadi Laba and Mai Ule. This Executive Committee is answerable to a General Meeting of all members, which convenes once a year. It consists of seven members, i.e. Chairperson, Secretary, Treasurer and four members - chosen by official election. Interestingly the election process led to the replacement of some of the old leaders with whom water users were not happy. The main objective of the SFA is to ensure the efficient operation and maintenance of the irrigation system, so that the members can make full use of the spate irrigation development. Secondary objectives are to make sure that members pay the annual fees for the system maintenance; to properly manage the funds of the Association; liaise with government; mediate in disputes between members and ensure adequate communication. The progress of the SFA was considerable, among others it raised annual fees (Nfk 500 or USD 40/ha) close to the full level of maintenance requirements of the ELWDP works. In addition it is coordinating maintenance and repairs to traditional structures, the monetary value of which is of a similar order of magnitude to the maintenance on the modernized structures. Another feature is that the SFA encourages richer farmers to support poor farmers by having them lend them their bullocks to undertake timely land preparation.

The experience in modernizing Wadi Laba and Mai Ule needs to be compared with the very different approach to the improvement works

Figure 12 Intakes and sluice gate to improved small system, Alebu (Gash Barka), Eritrea.

carried out in the nearby Wadi Labka by the Ministry of Agriculture without any external design support or fuinding. Initially, as the floods were emerging as a concentrated flow from a narrow gorge, flow splitters were constructed downstream from the gorge to reduce the size of the floods by separating enough flow into two or three separate river courses. These were then linked with several gabion guide bunds that were used direct the several channels of flood water to the different command areas on both sides of the very broad river bed. The location of these guide bunds was based on the traditional bunds but the riverbed material was reinforced and protected with gabions and the bunds were extended further upstream to meet with the flow spitting structure. Gabions were also used to construct a protection bund on the left bank of the ephemeral river to reduce the possibility of meandering and to ensure flow to all offtakes. The total costs of these head and intake control works amounted to USD 440,000 or USD 110/ha which is considerably less than the USD 2500-4000 per hectare reported for the modernisation of the She'eb systems. Originally, the modernisation of the Wadi Labka systems was included under ELWDP project adopting the same concept of a modern permanent diversion weir, breaching bund, gravel trap and a very long siphon across the river bed. However, after the escalating costs of the first two systems, this scheme was dropped for both financial and technical reasons. In hindsight, the comparison of the two approaches shows that a river engineering approach based on traditional spate flood management and less permanent structures is :

- Very cost effective in capital costs terms (the annual maintenance costs and the sustainability of the Wadi Labka systems had not yet been accurately assessed);
- More closely related to local technical capacity as it is based on the traditional system of splitting, diverting and managing spate flood flows;
- In line with existing traditional water rights;
- Effective in dealing with very large flood flows as part of the main diversion structures will breach ensuring that the floods remain within the main Wadi river bed and thereby protect thing the command area damage and erosion.

The Western Lowlands of Gash Bark is the other area where there has been intense development of spate irrigation systems in Eritrea over the last two decades (currently reported to contain 8,000 ha of land). In contrast to the Eastern Lowlands there is no tradition of spate irrigation in Gash

Barka. The potential is large[7] as the floods are less violent (most developments are based on minor tributaries of the main river systems) and because the spate systems provide supplementary irrigation to an area already developed with rainfed cultivation. In recent years, mainly the Ministry of Agriculture has developed a number of small flood diversion structures - with the help of international funding. The interest in developing the new spate systems in many cases has come from the policy of settling return refugees from Sudan and from improving food security. The newly developed diversion structures of Gash Barka consist of soil bunds, ungated masonry/concrete weirs and gated weirs. Since 1994, 26 schemes have been developed - with a total command area of 16,000 ha. On average there are 150 families per scheme (Ministry of Agriculture 2007). The approach adopted has not followed the pattern of Wadi Labka and has resulted in designs that have caused in many cases excessive sedimentation and low levels of water management.

Command area development in the Western Lowlands differs substantially from that in the Eastern Lowlands. Whereas in the latter situation, all fields are bunded allowing water to be temporarily impounded before being released to the next field in the field-to-field system. In the Western Lowlands, water distribution utilises main distributary canals with gated outlets to the field blocks. Guide bunds are used to spread the water over the already planted block command area. As the system provides supplementary irrigation, water is not retained in field by ponding. Less water is conserved in the soil profile but the system of more frequent irrigations is suited to the much wider range of pre-planted crops. Similarly significant accumulation of deposited alluvial material does not occur, as in the Eastern Lowlands however significant sedimentation has been recorded within the canal systems as a result of overflow canal structures and gated outlets.

The high crop yields of the Eastern Lowlands are not attained in the Western Lowlands, Although sorghum is not the principal crop in these areas, there is considerably potential to increase the average rainfed sorghum yield from the current level of 450 kg/ha to the much higher yields indicated from crop cuttings by the Ministry of Agriculture (1200-2100 kg/ha). This maybe compared to yields of 3,000-4,000 kg/ha in the Eastern Lowlands. Ratooning is not common in the Western Lowlands. Short maturing (60-70 days)

Figure 13 Guide bund to spread water over command area, Alebu (Gash Barka), Eritrea.

varieties of red sorghum are most popular, as these are least susceptible to moisture stress.

As with other areas where irrigation development is relatively new, there is considerable scope to improve field level water management and attain much higher yields in Gash Barka (Nawaz 2007). Opportunities for improving agricultural productivity exist in these areas of Gash Barka through intercropping and introduction of leguminous crops; introduction of multipurpose tree crops; better weed control and crop rotations; introduction of improved sorghum varieties; mulching for improved moisture conservation and strengthening crop-livestock linkages through the introduction of small scale fodder sorghum. In addition to these enhanced crop water management, there are also technical improvements that need to be considered such as the greater use of flap gates and improved earthen structures; the redesigning canals to accommodate higher flood discharges; redimensioning (enlarging) drop structures and providing drainage facilities with excess water collected in down stream ponds.

2.3 Spate Irrigation in Sudan

Spate irrigation in Sudan has a different history from Eritrea and Ethiopia. There are a number of farmer-developed systems throughout the country with different backgrounds. During the time of the British colonial administration at the start of the 20th century, however, some very large spate irrigation systems were developed for cotton production in the Eastern part of the country – in particular the Gash and Tokar systems.
Both are supplied by major rivers originating from Eritrea - respectively the Gash and the

7) *Mehari and Tesfai 2003 estimate the potential for spate irrigation in Gash Barka as 50,000 ha.*

Barka with the former ending in an inland delta and the latter in delta system close to the shores of the red Sea. Both spate irrigation systems were originally developed for cotton export however, their fortunes drastically changed over the years with the decline in demand for cotton and the change to sorghum (Hamoudi 1987). The type of water management system in Gash is very different from that in Tokar with the former relying on a network of seven main canals and numerous smaller Mesqa offtakes. In the Tokar system, no canal system exists with the floodwaters irrigating the land as sheet flow guided by small bunds, an approach that requires a high level of land and water management and considerable discipline from the farmers.

Spate irrigation exists in other parts of Sudan such as Khor Abu Habil in Kordofan and Derudeb in the Port Sudan area This section describes these two main systems first.

2.3.1 Gash[8]

The Gash River extends some 121 Km from the border with Eritrea down to the Gash die Delta, some 91 km north of Kassala town in Kassala State in the east of Sudan. Most flows occur between July and September and comprise a series of flood flows that are often superimposed to give very high floods that have been estimated at around 1,000 m3/sec at Kassala Bridge. The average annual yield has been computed at 1,000 million m3 and this is the main source of water for irrigated agriculture and domestic use (through recharge of the alluvial river bed deposits and accompanying aquifer). The river has caused much damage during times of excessive floods and the staff of GRTU have noted that the frequency of occurrence of high floods has increased noticeably since 1983. Flood disasters have now become a major threat to human life and property in Kassala City and villages neighbouring the water course.

The Gash spate irrigation system is located just south of Kassala town and extends north to the Gash die. It is served by seven main river intakes located along the left bank of the Gash river supplying a gross area of 240,000 ha. The landform is generally flat with an average slope of 0.1%. The Gash river in Sudan is characterised by very high sediment loads (coarse and fine sand and silt) averaging about 5.5 kg/m^3 [9] at Kassala Bridge. The hydrology of the river differs from other spate systems in Yemen, Pakistan and along the Red Sea in that flow in the river is normally continuous over a 3 month period with the overall hydrograph being the envelope of many smaller hydrographs. In the past these overlapped giving continuous high stages over the flow period. In recent years runoff has been less frequent and have resulted in a series of closely connected but separate hydrographs that resemble those of the traditional systems in Yemen. This necessitates a type of water management that differs from other spate systems but that has some common characteristics.

The population consists of an estimated 87,000 mainly rural households comprising around 500,000 people. Their communities live in small townships focused on Gash river and flood plain and along the old railway line and more recently the main road to Port Sudan. The Hadendowa, the largest of the Beja ethnic group, is the major tribe and consider the Gash Delta as their heartland claiming traditional land rights over it. During the last century they have increased their holdings in the area, mainly due to the control on flood flows provided by the Gash spate developments and the subsequent increase in productivity of the land. The tribe consists of semi-nomadic pastoralists who rely primarily on livestock with the agriculture as a limited secondary activity providing fodder for their animals and staple grain at subsistence level. Other smaller ethnic groups include nomadic pastoralists and sedentary agriculturalists and horticulturalists.

The irrigation system in the Gash Agricultural Scheme (GAS) command area comprises main, link and some branch canals fed from the Gash River by means of gravity offtakes fitted with stop logs. The flows in these gravity canals are divided between a large number of misga or distributary canals that directly supply the agricultural land through breaches in the canal banks. The spacing of the offtakes to the misga canals varies from 750 to 1,000 metres, depending on the soil type, with misga blocks having an average command area of about 3,000 feddans. Unit flows are high and these move across the *Misga* blocks as a wetting front contained by inter misga bunds and following the line of least resistance and guided by Misga water workers who are instructed by the *Sheikh al Misga* or water master[10]. The design of these systems was first developed in the 1930s

8) *This section draws heavily on IFAD (2003). Gash Sustainable Livelihoods Regeneration Project (GSLRP). Appraisal Report. Working Paper 2: Natural Resources, Land use and Farming Systems and Anderson (2008), Working Paper on Irrigation Infrastructure Rehabilitation and Water Development GSLRP, Mid-Term Review.*

9) *Sediment deposition in Gash is 129 mm annually - which is twice the volume in other comparable systems.*

and improved upon in the late 1950s. They were originally developed for the cultivation of cotton using flush irrigation[11] techniques that maintain the high flow velocities through the system to reduce deposition of the considerable amount of sediment that is transported by this river[12]. This flush approach recognised that flow velocities in the canals need to be maintained and that structures at the head of each Misga should be designed to pass as large a flow as possible to take advantage of the sizeable flood flows of short duration that occur in the Gash river.

Irrigation water is drawn off from the left bank of the Gash river through masonry headworks into the main canals. These are designed to take a full supply that varies from 10 m^3/sec (Fota) up to nearly 60 m^3/sec (Degain) although the maximum discharge in the original systems was 20 m^3/sec. The head regulator/offtake is a strong (masonry) structure consisting of brick abutments and piers on a reinforced concrete slab. There are 2-3 or sometimes more openings that are 2.5 m in width and that can be closed by 9x3 inch sunt timbers, which can be dropped into grooves in the brick work. These are operated by simple lifting hooks and are inserted to ensure that bed load does not enter the canal system from the Gash. The regulators are 3-5 m in height and are provided with heavy stone protection of floor and side slopes both upstream and downstream and these slopes are normally 1:1 with pitching 0.25 m thick and a smooth finish. An access roadway is carried on top of the piers by rolled steel joists or brick arches in the older designs. As the river levels have increased over time, the invert at the offtake and outlet to the canals have been raised from time to time to ensure that bed load sediment is restricted from entering the canals.

The type of regulator provided along with the management system derived over time has the great advantage of drawing off only comparatively clean top water from the river. The staff managing each offtakes during the flood season comprises 7 to 10 persons under a foreman, who works to a fixed downstream staff gauge to maintain full supply in the canals with the water depth usually being about 1.5 m. The correct siting of the head regulator is very important and has been located on the outside of a gentle stable curve and inclined to present a tangential upstream face in reference to the flow of the Gash river, and an abrupt downstream nose. This obstructs the natural flow lines of the river causing back currents and eddies that induce good flow conditions at the entry to the canal giving comparatively clean top water. The same principle applies to the siting of *misga* offtakes in canal (see below).

Open masonry *misga* head structures are preferred over pipe structures as they not only can accommodate larger flows more importantly limit flow restrictions that would encourage sediment deposition. Most sediment is thus carried either onto the *misga* fields or into the *haffirs* located at the tail end of the main canals. Traditionally *misga* head structures were located so that flow entering the *misga* fields created a wide spread and resulted in most silt being deposited almost immediately on the field. Although this caused a gradual loss in command at the top of the *misga* block, as land was not allocated to any single person but on an annual lottery system, as it came out of command, it was replaced with additional land further down the *misga* block. Overtime this has meant that a *harram* area of about 10-30 m wide now exists between the main canal and the *misga* blocks in many areas.
Floods in the Gash River usually come in a number of “flushes” that are divided into early and late flushes. The early flush which is denoted as the first rotation or watering takes place around the last week in June and ends towards mid-August. The late flush, or second rotation, extends from about mid-August to mid-September. Between the flushes, intervals occur but water levels in

Figure 14 Fota Intake: silt-laden floodwater, Gash, Sudan.

10) *The main factors affecting its progress are slope, nature/texture of soil, surface characteristics & its covering.*
11) *This is a variation on spate irrigation that utilise fluctuating run-off in the seasonal Gash River. See the Recorded Behaviour of the River Gash in the Sudan, C.H.Swan, Chief Engineer, Gash Board, 1954-55. Ministry of Irrigation and Hydro-Electric Power, Khartoum. 1959.*
12) *5% by Volume.*

the canals are more or less maintained through adjustment of the stop logs at the intakes on the Gash River. Thus the instability in River flow is not reflected to the same degree in the irrigation system. The early flushes take place during July and are used to cover about two-thirds of the targeted number of *misgas* for the season[13]. The remaining *misgas* are then irrigated in the second rotation. Within the targeted *misgas*, water is supplied systematically from the top to bottom for a period of 25-30 days. The upper parts receive more water[14] particularly as all water supplying the first 1/3 of the *misga* passes over this land. For this reason, these parts of the *misgas* were planted in the past with cotton or higher value crops that need more water than sorghum[15] that were planted in the remaining areas. Unlike other spate systems where post irrigation planting is practices, water is delivered to the soil moisture reservoir in a similar manner to broder strip irrigation rather than impounding. Once a *misga* has received its required water, the *misga* offtake is closed with cultivation beginning after about one week, as soon as access to the land for machine (or hand) planting can take place.

Misga offtakes are "paired" throughout the Gash system to maintain flows within the capacity of the canal systems and to ensure better equality of land for farmers. This means that in any one year only a maximum of 50% (or 120,000 *feddans*) of the total command area is irrigated. This is called the target area for irrigation. The difference between area irrigated and actually cultivated indicates the level of water management both at *misga* level and at scheme level in terms of delivery of water to the *misgas*. In recent years, some blocks (*mekali*) have achieved high ratios (>90%) but there is still considerable scope for improved water management on all blocks. Under the GSLRP modernisation of the system, the crop rotation was reduced from 3 to 2 years to increase the area of land under cultivation per year and to benefit a greater number of farmers. Although there are disadvantages in the 2-year rotation relating to weed growth and mesquite development, these are outweighed by being able to accommodate many more farmers than was possible under the past 3-year rotation.

Figure 15 Flow divider at Makala channel, Gash, Sudan.

Formally, the land in the Gash is owned by the government. The development of the scheme in 1924 was preceded by regulation of the previously existing forms of land and natural resource ownership based on customary common property arrangements, vested in tribal institutions, and its replacement by the government as the legal land and water owner in the Gash. The Gash Land Law 1918, which is still valid, states that government is the legal land and water owner although farmers maintain traditional user rights that are recognised. Ambiguity prevails because these are not formally registered.

The average tenancy in Gash up to 2000 was less than 0.5 hectare. Because of restrictions in the supply of irrigation water, through poor maintenance of the system, only 10% of this allotted area could be farmed - clearly insufficient to ensure household food security. This was aggravated by the inequitable distribution of land where 60% of the land is held by 3% of the farmers, namely the tribal leaders of the Hadendowa clans, and allocation of land only within a *misga* block - farmers do not have tenancies on a permanent portion of land but move from one site to another within each clan's irrigation block. Tenancy rights are administered by the sheikhs of each clan and for each crop year, land within the *misga* is allocated by a lottery system based on the proportion that was actually irrigated with less influential farmers receiving smaller proportions of land to cultivate

13) *Under the 2 year rotation system, about 50% of the Misga area is irrigated in any one year and is referred to as the target area. When the flood season has passed and the irrigated area has been plotted using the Gitta system, the final irrigated area is defined (around 80-90% of the target area in a good and well distributed flood season). The actual cultivated area will be less than the irrigated area (about 70% of the target area) due to inadequate irrigation at the peripheries, non-allocation of land and other technical/social constraints.*

14) *Aimed at 5,200 m3/feddan in the past, which from past experience is suitable for a crop of cotton planted soon after the end of the water application period*

15) *Aimed at 3,200 m3/feddan, which from past experience is suitable for a crop of sorghum planted soon after the end of the water application period.*

and parts that had not received a good level of irrigation.

The allocation of land has been under severe stress since the extended drought in the mid-1980s. While the irrigation scheme was originally designed for 12,000 tenants, the number of tenants over the years has come to exceed 50,000. To add to this there is pressure on the limited land resources from the nearly 47,000 households that have migrated to the terminal flood overflow area at the end of the system around Gash Die.

As mentioned the system was originally developed for cotton production and the Gash Agricultural Scheme organization was established in this period - taking care of irrigation system management but also cotton ginning and marketing. At that time (as in spate systems in South Yemen in the same time) pre-irrigation land preparation was done - eradicating bush growth, loosing the soil and making moisture-seeking furrows - all to maximize the infiltration of water. Cotton however disappeared from the cropping system in the 1960's as a result of mounting international competition. In the 1980's castor was introduced and became the crop of choice. At present, however, the main crop grown by the semi-sedentary pastoralists and tenant farmers is sorghum and the system has effectively moved from export production to fodder production (sorghum stalks) and self-subsistence. The balance water of the canal system goes to the interior delta - the Gash Die - where it sustains newly cultivated and irrigated land, rangeland and forest.

Since 2003 the Gash Project has been rehabilitated with funding from IFAD. The Gash Sustainable Livelihoods Regeneration Project (GSLRP) is an example of a broad-based approach to the improvement of spate irrigated areas. In addition to the main component involving the rehabilitation and upgrading of the diversion structures and canals in the spate command area to overcome past poor maintenance and siltation of the systems, improved water management (both at system and *misga* level) was included along with flood protection works in the vicinity of Kassala town. Other elements in the project were the creation of WUAs, agricultural extension services, livestock vaccination, land allocation and eradication of mesquite that had - as elsewhere - infested a large part of the command areas. One of the most ambitious components was the program of land allocation - i.e. providing individual land titles: complex because of the informal ownership of clan leaders and the large number of tenants.

Midway through the project, positive impacts on household nutrition, food security and household assets were recorded - even though main challenges concerning WUA creation, land titling, effective annual maintenance, payment for O&M and flood protection works remained:

- The number of underweight children decreased from 53% to 40%.
- The number of household owning small livestock increased with 7%. The support to livestock health and livestock production was leading to an increase in herd size, decrease in disease incidence, and increase in milk production.
- The number of households cultivating land increased from 70 to 79%. Crop productivity increased especially in the rainfed agriculture. The cultivated area under spate irrigation increased.
- There was an increase in cultivated area under spate irrigation from an average of 16,000 feddan in 1990-2003 to an average of 60,000 feddan in 2004-2007.

However, due to the intense population pressure and slow land reform, the increase is not yet sufficient to sustain food security and to generate surplus cash. Moreover, predicted returns from water charges for the recovery under the traditional sorghum based farming systems but with improved varieties being increasingly grown

Figure 16 Gate operators explaining flood level at Hashera, Gash, Sudan.

indicates that Misga level O&M costs can be met by the farmers with some proportion of the main system charges also being funded. Annual costs of regular canal desilting in recent years has been high, and much of this has resulted from over excavation of the canals and a lack of understanding by the engineering staff of the levels required in the canals for good operation. A methodology for training and upgrading the quality of engineering support for O&M has been proposed however, if not accepted by the Gash Board, will result in the past high O&M costs and present a serious constraint to the long term financial viability of the GAS. The main factors that hinder the project from achieving a significant impact on food security and incomes are:

- The average cultivated area though already increased importantly was still below the planned 50,000 ha and the average area cultivated per tenant is estimated to varied between 0.2 to 0.6 ha / year below the 0.75 ha/ year target.
- The large number of tenants considered eligible - perpetuating a system of mini-holdings - but inflated by the large number of extra members of the same extended family
- The limitations to the effectiveness of the WUAs due to the very slow pace of land reform. As has been shown in those blocks where land titling has been carried out successfully (*mekali* block), if this is resolved and land titling is effected, the uncertainty relating to role and authority in *misga* level management including water management, water fee collection and maintenance will be resolved. Without this, the current low levels of collection of water fees will persist.
- Persistence of sorghum farming using traditional varieties. Some parts of the Gash scheme have adopted new sorghum varieties and additional alternative crops grown on residual moisture. In these areas relatively good returns are achieved. For those areas where land reform has not taken place, traditional practices are adopted and the associated low levels of return achieved. This constraint to improved development is reflected in the small number of beneficiaries taking advantage of rural finance services to small producers (only 1.6%). Low productivity farming thus persist in the area.

The main challenge that is reflected in the performance of all components is the land distribution. Because of the ambiguous land title situation and the involvement of large landholders, distribution to cultivators proceeded considerably slower than expected. After 4 years the process of land titling providing permanent land titles of 1.2 ha was underway in half of the project area (Egemi 2007). This is the first step and effective WUAs and good engineering management of the O&M of the systems is essential to move the new owners of the land from traditional to modern farming practices and crops. Although anticipation in the blocks not yet covered is high, the process is being strongly resisted by a very few highly influential Hadendowa leaders who are also opposed to the policy of allocating 10% of the titles to poor female headed households.

2.3.2 Tokar

Tokar must rank as one of the most complicated spate system anywhere in the world. The total irrigable area on the Tokar Delta is around 80,000 hectares with the peak use amounting to around 52,000 hectares - which was in the early part of the last century. Over time this has been reduced significantly with only about 12,000 ha sown in 2007-2008 season (Anderson 2008). Originally the scheme was also developed for cotton, but as with the Gash system, this crop became unviable for small holder farmers and other than a quota of cotton enforced by government, nowadays farmers mainly grow sorghum and millet for which they can afford the inputs.

The Tokar Delta is the outwash fan of the Baraka River (Barka in Eritrea) on the coastal plain of the Red Sea some 150 km south/south-east of the Red Sea state capital Port Sudan. The Delta covers a gross area of about 406,000 feddans (170,520 ha) of which about 40% (160,000 feddans) has been irrigated in the past. The Delta is divided into three parts, the Western, Middle and Eastern Delta areas with the central area forming the main part of the irrigation scheme. The town of Tokar is located about 35 km from

Figure 17 guiding water acrosss huge fields with small field bunds, Gash, Sudan.

Shidin Rock, a local land mark on the Baraka River upstream from the main Tomasin diversion bund.

The Delta has been extensively cultivated primarily for irrigated cotton production for more than 100 years with cotton that was introduced by the British colonial administration during the First World War. This administration distributed Tokar Delta Land on a tribal basis and as population densities were low, relatively large landholdings were initially provided with some redistributed in 1934. Land holdings are now organized on tribal basis and each family has land allocated on each of the three deltas[16] with the land survey division of the Tokar Development Corporation being responsible for mapping agricultural plots and farms. The soils of the Tokar Delta comprise fertile silty deposits close to the Barka river and its past flood routes, mainly in the Middle Delta and sandy soils to the south (Eastern delta) and saline silty clay in north-eastern parts parallel to the sea (Western Delta). Scattered across all parts of the Delta there are raised areas of migrating sand dunes.

Local dune and sand ridge formation is a major challenge in Tokar. With the numerous and forceful erosive winds that blow across the Tokar scheme, all stalks from the sorghum and other crops need to be removed after harvesting in order to provide no restriction to the wind that can and will transport much soil. In the past, regulations existed to ensure that all farmers complied with this or were fined for failing to carry out the work. Repeated offenders were expelled from the scheme as their lack of diligence impacted on all farmers. When sorghum stalks are not removed (as has been happening over large parts of the scheme), small mounds up to 0.60 metres in height develop and this significantly hinder the movement of sheet flow and hence the irrigation of the land. Small gullies and channels are formed and water distribution is extremely uneven. In the past, clearing of the land of all obstructions after harvesting and the levelling of the land before irrigation enabled irrigation by sheet flow. This is not a common form in spate systems but in Tokar it was very effective in the past. The layout of the scheme was established about 80 years ago when the area divided up using the same system of delineation adopted in Gash - which was developed at the same time.

Figure 18 Gash, flood yet to reach Umbareisi-Metateib intake, Gash, Sudan.

Although the amount of land irrigated depends upon the availability of flows in the Barka River, there has also been a decline in land cropped due to the presence of mesquite trees, very poor land management that has created and uneven topography that makes water distribution very difficult and a lack effective overall management. Historically, the cropping pattern was 80% cotton with 20% sorghum grown to protect new cotton seedlings from the Hababai wind and provide fodder for agro-pastoralists. Millet was cultivated on the sandy soils with in lower moisture holding capacities. Recently, vegetable production has been introduced in response to the declining prices of cotton. With the aim of maintaining an important cotton production, the board of the Government-controlled Tokar Delta Agricultural

Table 2 Cultivated Areas within Tokar Scheme

Season	Area (Feddan)		Crops Grown			
	Irrigated	Sown	Cotton	Sorghum	Millet	Vegetables
2003-04	102,485	38,103	7,790	12,123	15,400	2,790
2004-05	38,726	25,226	4,052	8,780	10,840	1,554
2005-06	65,340	42,600	4,400	20,012	15,600	2,588
2006-07	49,405	44,709	4,020	21,744	17,845	1,100
2007-08	67,570	31,405	3,912	11,425	14,195	1,873
2008-09	0	0	0	0	0	0

16) *For more details refer to SPCRP Model Project. TOR. Appendix 1, Tokar Delta Rehabilitation Project (TDRP). European Commission. 2008.*

Scheme (TDAS) used to make it compulsory for farmers to the largest part of the plant most of their land area with cotton. However, without the provision of good quality seeds and other inputs together with the appropriate ginning and marketing facilities, it has not been possible to enforce this. Sorghum is the main crop but yields are low. Farmers prefer to grow sorghum to meet their own food needs and also for feeding their cattle. The share of cotton in the cropping pattern is actually much smaller than 60%.

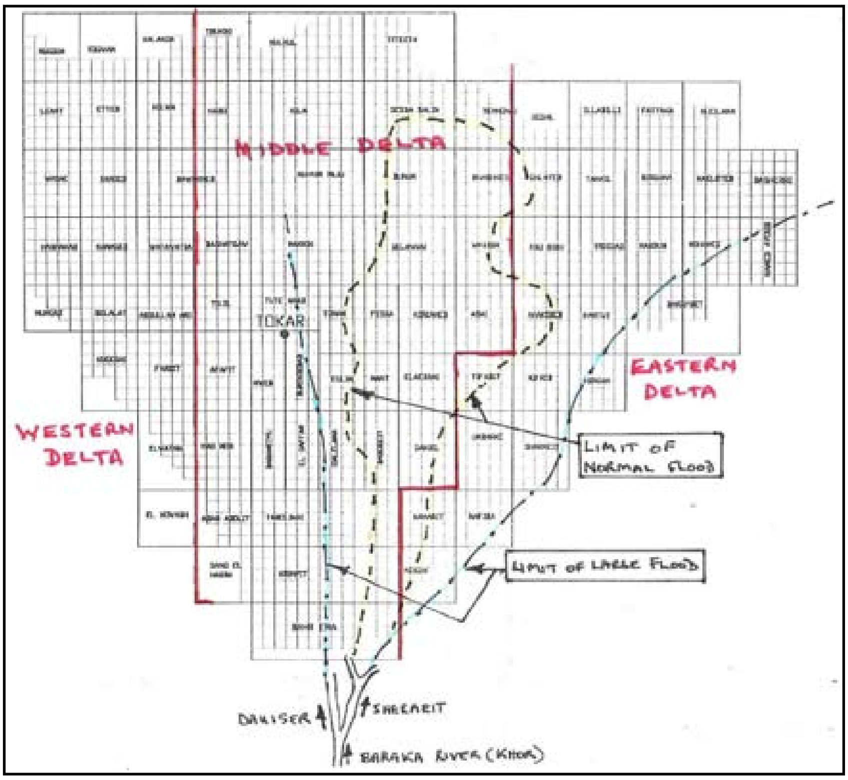

Figure 19 Topography of Tokar Delta.

In the extremely flat topography of the area water management consists very much of guiding the sheet flow. A main feature in Tokar is the Tomosay diversion bund and the Tomosay Embankment, which begins on the left (western) bank of the Baraka river and extends for about 50 km along the Western limit of the scheme and then turns eastward to provide a limit on the North side and restrict outflows to the sea. There are also guide banks on the Eastern Side of the irrigated area. The embankment has been built to act as a guide to flood flows to contain them within the Middle Delta, the most suitable land for irrigation, and to limit the spread of the annual floods to the better lands and thereby ensure that adequate depths of irrigation are provided within the irrigated areas. The second and important function that the Embankment provides is to protect Tokar Town from large floods, particularly as it is now 2-3 metres below the irrigated land in some places. This fairly typical in spate areas, because command areas rise faster because of sediment deposition.

In recent years, the river and irrigation infrastructure has deteriorated and become inefficient. In critical areas the earth embankments used for protecting the banks of river channels and diverting the flow of flood waters to the agricultural lands are not reliable, leading to

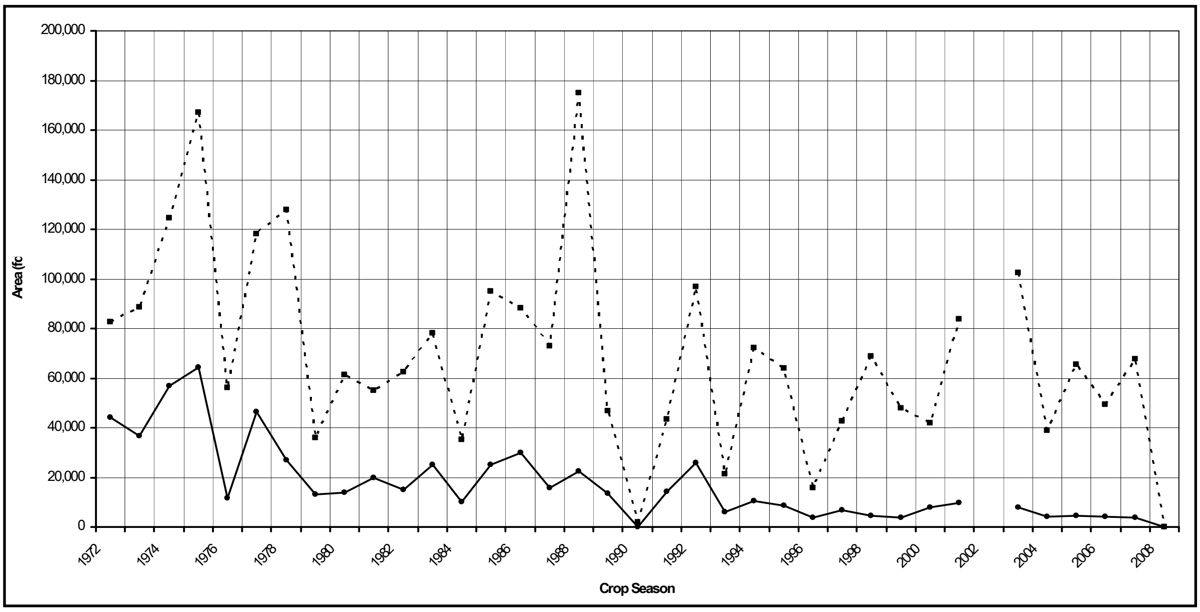

Figure 20 Tokar irrigated areas.

considerable losses of irrigation water. Much of the works undertaken by the Government (TDAS) have been constructed using force account as and when machinery becomes available. No surveys and engineering designs are made and there has been limited scope to introduce more appropriate spate type lower cost structures. This gives the works a limited lifespan and many have to be repeated every 1-2 years.

The system of irrigation adopted in Tokar is flood irrigation supplied by short main channels of unclear cross sections. There is no system of canalization with associated headwork and distribution. Flood flows are diverted to these short channels by using seasonal bunds built across the Baraka River at the head of the Delta with the main bund being the Tomosay bund. Water is then directed over the land as sheet flow which in the past spread evenly as the land had be cleared of any crop residues, bushes or other obstacles that would create uneven land forms and split the sheet flow. The alignments of these supply channels has changed with time and effects of floods and sediment deposits and in some places they have become braided and less well defined.

All of the flood water from the Baraka River is diverted in turn over the land starting with the Eastern middle area that is now higher than the western middle area at the Tomosay bund. When sufficient water has passed to this area, or when the Tomosay bund breaches, water is allowed to pass down to the Khor Tomosay and to irrigate the remaining area. The force of the flood and the lack of any division structures means that, when floods pass down the Khor Tomosay, they are always likely to threaten the Tomosay Embankment, particularly as the deposition of silt with time has meant that the lateral slope of the Delta is towards the embankment. Deflector bunds that push the flood water away from direct contact with the embankment are built and repaired annually and these also assist in to spreading the water more evenly over the agricultural land. As was the case with the Gash irrigation scheme, the soil moisture reservoir is replenished by the water infiltrating from the passage of the sheet flow over the land. No small bunds for ponding of the water on the irrigated land are allowed with bunds created only to guide the direction of overland flow.

To overcome the uneven topography, guide bunds are used to deflect the water from the small Khors that have developed throughout the irrigated area and these then spread the water onto the less dissected land and cause some beneficial siltation in the Khor channel. However, these result in patches of land that remain inadequately irrigated. In addition, where the topography is uneven, the water finds a path between the mounds and often results in land unsuitable for cultivation. Over time, gully's have developed in the areas that used to be covered by sheet flow. This has required the building of temporary division embankments across these gully's but there is a precarious balance. The failure to remove sorghum stalks has encouraged sand dunes and mounds that in turn inhibits sheet flow and results in uneven water distribution.

To guide the water across the fields where high points existed, small guide bunds are also used. The location and shape/ length of these bunds relies heavily upon the local knowledge of the irrigation technician who advises farmers of the measures that he has taken to ensure even distribution of irrigation water and those measures that farmers need to take to improve water delivery, such as levelling of the high spots in their plots. When 50 cm of water has been received, this is regarded as sufficient and water is diverted elsewhere.

Figure 21 Bera tentcamp, Sah, Sudan.

Figure 22 Tomasay Bund reinforced with sand bags, Tokar, Sudan.

Figure 23 Guide bund to spread floods: very difficult as sand dunes and sand depositon create many obstacles, Tokar, Sudan.

2.3.3 Khor Abu Habil

Khor Abu Habil is situated in Kordofan. Most production is self-subsistence: millet, beans, sesame, and hibiscus. In addition some cash crops are grown: cotton, corn, tomatoes, beans and some vegetables. Also grown in some areas, vegetables and fodder. Other location specific sources of income are the collection of forest products, charcoal making and brick production.

Most families are into livestock keeping. The majority of families owns goats or sheep, donkeys, and cows. The animals live of the crop residues and in addition fodder is grown. The entire area of Khor Abu Habil project is rich with considerable numbers of the different classes of livestock, being a summer grazing area for Baggara tribes on the southern side of Khor Abu Habil and a migration route for the Shanabla tribe with their camels and small ruminants. However,productivity under the traditional systems is very low. Milk yields from local cattle types (Selaim and Baggara) range from 3.0-4.0 liters/day (5 lb), 5.0-7.0 liters/day (10-12 lb) for Kenana and Butana cows and 10-12 liters/day (25 lb) for crosses with foreign cattle (Friesian x Kenana crosses). Daily milk yields for Desert and Taggar goats in the project area are very low and rarely exceed one pound. Productivity levels in Desert (Villages on the northern side of Khor Abu Habil) and Shorani sheep (in villages on the southern side) are low too, reflected in low conception and lambing rates and high ewe and lamb mortality rates and late age at first conception and lambing.

2.4 Spate irrigation development in Somalia

Irrigated agriculture in Somalia is largely concentrated in the south, along the Juba and Shabelle rivers. In the extensive alluvial plains there are several types of irrigation systems: (1) lift irrigation systems, small-scale and often family-owned, irrigating (2) perennial gravity systems - especially along the Shabelle - some quite small scale and some depending on gated intakes, cultivating maize but also horticultural crops and (3) a mix of flood recession farming and spate irrigation (called deshek) - particularly in the lower part of the rivers (SWALIM 2009).

The flood based system in the Juba and Shabelle tracts is a mix of flood recession farming, inundation canals and spate irrigation (FAO 2008). The main season is the gu - from April to June. Flood based farming is practiced from 500 m to up to 30 km distance from river. It includes areas along the riverbanks, which are often called riverbank farms (5-100 m from river). When the bi-annual floods begin to recede farmers plant maize in depressions and dry river branches, particular along the middle and lower reaches of the Juba. This system is risky as the floods can return before the crops are harvested. The areas are flooded through levee or embankment overtopping using water intakes through man-made openings along the river. In some areas additional water is pumped. The total

Figure 24 Flooded fields, Shabelle, Somalia.

area under deschek is in the pre-disturbance period was estimated between 110,000 to 150,000 ha (Basynat and Gadain 2009). The specific component under spate irrigation is not clear but is probably not the larger part.

There has been considerable damage caused by years of neglect of both river embankments, barrages and canals. This caused of drastic decrease in the irrigated area - particulary of the perennial systems - and more uncontrolled flooding. The rehabilitation of the major irrigation, drainage, and flood control infrastructure in Middle and Lower Shabelle and Lower Juba are high priorities, but would ideally require an integrated approach as the water management along the rivers are highly interdependent. Also land disputes stand to be resolved.

Riverine farmers normally get the majority of their food and income from the production of irrigated food and cash crops. Poorer groups often have good casual labour opportunities on other farms, and also engage in petty trading and the collection of bush products. This group tends to have very small herds or no livestock at all. Riverine resources, such as fruit trees, wild foods and small bank-side plots can be important assets too. The group of riverine farmers suffered for two main reasons from the political disturbance (Montani and Majid 2002). Firstly, in many areas, riverine groups are politically marginalised, vulnerable to intimidation by well mobilised pastoralist militia. In some areas, riverine groups have been forced off their land holdings when mutually beneficial alliances have not been created with their pastoralist neighbours. Secondly, heavy flooding, combined with the decrepit irrigation infrastructure, creates a constant risk.

In the dryer northern part of Somalia irrigation is more scattered, depending on the local availability of dependable water sources. Small-scale surface irrigation is practiced mainly in dry riverbeds or adjacent areas, using water pumped from shallow wells and in some cases by tapping the sub-surface river flow directing it through channels into the fields. These farms are usually small (less than 2 ha) and produce mainly fruits and vegetables for local markets. There is spate irrigation too in these areas but it is not widespread. Floodwater is retained within the streambed or diverted to adjacent fields for sorghum and maize and some cash crops, with a commands usually of less than 10 ha.

Such spate irrigation system were for instance introduced in Togdheer (Somaliland) in the late 1950’s and 1960’s, e.g. Beer, Odweine, Haahi, Getitaley etc. Rainfall occurring in the Golis Range Mountains to the north of these areas discharges flood water to the said areas through seasonal watercourses (togga).
The agro-pastoralists in these areas prefer to grow the short term maturing sorghum variety, maize and pulses. They also harvest hay that serves as fodder for export animals (Candlelight/ FAO 2006). The civil war played havoc with these systems.. At Beer, the colonial British administration had constructed a structural weir across the Togdheer togga and diverted flood water to

an off-take channel that conveyed water to an agricultural scheme of 600 hectares. The floods were controlled with sluice gates fixed on the weir, the off-take channel and the conveyance canals. The scheme was a pilot project established in a previously completely pastoral region and served 800 households who cultivated the land on cooperative basis. Following this example with German support other new systems were created in the area on similar lines serving cooperatives with an area of more than 3000 hectares that continued to produce crops at a surplus of their needs. Also elsewhere similar new systems were created – for instance in Ceel Bardaale, located 70 kilometer from Arabsiyo, – where the land was held by a religious community that had negotiated land rights with the surrounding pastoral groups. The system, consisting of masonry diversions, flood canals and field control structures, was constructed with support of USAID in 1964. This 45 ha received its main income from the cultivation of qat – besides the return from fruit, vegetables and fodder. An evaluation in 1985 comment on the very high rate of return of the investment (McCarthy et al. 1985).

Several of these minor system have fallen (partly) into disuse in the period of civil strife , because the diversion and canals have fallen in disrepair and because tillage capacity was lost due to loss of draught animals and tractors. Also because of the low market price of cereals, the farmers' preference to agriculture declined making them more inclined to livestock husbandry, charcoal production or a reliance on food aid. In addition traditional sorghum seed varieties have been lost.

3 Unlocking the potential

Spate irrigation for supplementary watering of crops is a growing phenomenon in Eritrea and Ethiopia, whereas in Sudan there is considerable scope to restore productivity to earlier levels through improved water management. In all of these areas spate irrigation operates in areas of marginal productivity affected by increasingly variable rainfall and where extensive rural poverty exists. If well designed and managed such interventions can make a substantial difference and support productive agricultural systems. There are several areas where spate irrigation has potential and could be introduced, particularly in the lowlands. This has happened over the last ten years in Gash Barka (Eritrea), where more than 20 small system now serve almost 8,000 ha. In Ethiopia similarly there are unused possibilities in the low land areas. The sustainability of such developments is uncertain as most designers have limited experience of designing sustainable spate interventions.

Spate irrigation, however, is 'different'. This shows from the description of some of the systems, for instance the fine and delicate balance of managing the Gash and Tokar systems in Sudan and the need for good overall management and cohesive and effective famer involvement. Engineering designs are dominated in most cases by the civil engineering approach to convential perennial irrigation. There are few design manuals to guide engineers and most approaches reflect the relatively limited attention paid to ensuring that technical aspects are correctly approached. With the relatively poor

Figure 25 Improvement in Flood Irrigation System, Shabelle, Somalia.

levels of success achieved in many conventional perennial irrigation designs and modernization approaches in Eritrea and Ethiopia shows, the prospects for spate irrigation face an uphill battle and reinforce the need to train engineers and produce clear and comprehensive spate Irrigation guidelines.

In unlocking the potential of spate irrigation in the Blue Nile countries there are a number of issues:

(1) Better mapping the potential of spate irrigation in the Horn

There are vast stretches of land where spate irrigation is possible but has not been tried. In theory large areas that border the escarpments in the Blue Nile countries and suffer from the effects of rain shadows may provide opportunities for spate irrigation but the potential has as yet not been systematically documented. It would be useful to do a systematic assessment - area by area[17] with the help of topographical information, rainfall data and field visits. In assessing the potential a wide range of techniques need to be kept in mind - diversion by permanent structures, river engineering approaches, flood spreading for rangeland improvement and groundwater recharge and others. The link with shallow groundwater would need to be established - as systems based on conjunctive use of groundwater and spate irrigation are highly productive.

(2) Promote designs that are appropriate for spate irrigation

The region has had its share of failed systems as inappropriate design concepts and designs were used. The special nature of spate irrigation is manifest in the different boundary conditions: capturing sometimes sporadic and often forceful flood events; making sure the very high and destructive floods do not enter the command areas and play havoc in it; dealing with high sediment loads; achieving a fair distribution of an unpredictable volume of water; avoiding the temptation to overstretch the command area and have many areas with very low probability of water gifts; coping in some areas with dune formation and mesquite infestation.

Where there is a local tradition of spate irrigation - for instance in Tigray in Ethiopia or the Eastern Lowlands in Eritrea - designs can be reviewed with farmers. After initial disappointing results spate irrigation designs for the Fokissa system in Tigray for instance were modified. A relatively wide off-take was used, which was aligned at an angle of 60 degrees and no gates were provided (Teka et al, 2004). This is just an example. By now a repertoire of design options has developed - specific to spate irrigation. This is summarized in annex 2 - but would always require local 'fits' - based on local situation and local priorities.

Another important point is that it is useful to keep a wide set of options open in spate irrigation development - not only and solely focus on the construction of new civil headworks. In particularly one should also consider:

- improving traditional structures, for instance by reinforcing traditional diversion bunds and intakes with gabion sections; creating permanent anchor and division points; creating flood splitting or flood spreading structures; using river bed stabilizers;
- making sure heavy equipment is available for work on diversion structures, soil bunds and improvements inside the command area;
- in general consider a 'river engineering' interventions - using the interventions above and avoid that the river breaches its banks and 'runs away' or that it is silting up considerably in some of its sections.

Finally, authentic systems of water management, as spate irrigation, requires the support of experienced engineers - familiar with the specifics of spate irrigation and able to understand and communicate water users. This however not easy - with career prospects for irrigation engineers elsewhere it is difficult to attracted engineers to work in these remote areas for extended periods. A particular problem in Eritrea is that many experienced spate practioners are not available in the country at the moment. What this requires is thought to grooming new field engineers working in spate, making the work attractive and strengthening the networking and exchanges of ideas and insights.

(3) Improving field level water management

There has been considerable attention for developing diversion structures that can cope with high sediment loads and forceful flood events. Yet more attention is required to water management within the command area as well as moisture management at field level, if only because the larger gains may be there. The She'eb spate

17) In Ethiopia the presence of many seasonal rivers makes flood utilization promising in Logia, Yalo Gulina, Tali, Dire Dawa and part of Somali Region.

irrigation systems in Eritrea for instance have very high productivity - reaching sorghum yields of 3500 kg/ha and higher. The key to this result is the excellent moisture conservation in the area. As the summer floods in the area arrive one to two months before the sowing season care is taken to preserve as much soil moisture as possible by timely ploughing as well as by planking. The soil composition is good and this makes it possible even in the high temperature of the She'eb area to have adequate soil moisture several months after the spate irrigations. Another important factor in Sheeb is the care taken to maintain field bunds. These look unassuming but they are essential in preserving soil moisture. They allow the flood water to infiltrate. Much care is taken to ensure the field bunds are strong enough and there are penalties for negligence, The reason is that if field bunds - unassuming as they are - would breach in an uncontrolled fashion not only can water not infiltrate in one's own field, but it will also escape in an unplanned way and may cause rutting and gullying in nearby fields. Such rutting destroys field moisture - as the field gullies act as moisture drains. Often the importance of moisture conservation is not well-understood.
In the ELWDP project in Eritrea for instance a component of restocking livestock (after drought and civil war) was discontinued so as to free financial resources for budget over run on the main diversion structure. The ample availability of livestock however was essential for moisture management as having draft animals of one's own makes it possible do the land preparation in time and develop strong field bunds - essential to preserve soil moisture.

There is scope in many spate irrigation systems in the region to make more of moisture conservation - especially in relatively new areas such as Gash Barka where water is now spread but not impounded even though sedimentation rates would allow, as well as for new systems in Ethiopia This applies both for areas with pre-irrigation planting and post-irrigation planting. In pre-irrigation planting the storage of soil moisture is important. In system with post-irrigation planting splitting the flood flow in manageable proportions is important. This is an area that can do with more systematic study.
Another lesson particularly relates to newly developed spate systems. The very good productivity in She'eb is explained by the relatively small size of the command area, allowing fields to be irrigated more than once. As was discussed this greatly increases water productivity and improves the level of cooperation between the water users. Command areas in new systems hence should not be over-expanded.

Apart from improvements to moisture management at field level there is also scope to work on improvement in the canal network. In Tokar (Sudan) for instance limited attention has been given to the possible improvements to the irrigation network. No canals exist in the conventional sense in the Tokar plains and instead water is conveyed through the lines of traditional river courses (Khors) and guided using earth bunds pushed up by bulldozer. These bunds are built from sandy material and sometimes reinforced with sand bags, yet they are still prone to failure in high floods flows anticipated in the Baraka River from time to time. They thus often fail at a critical time in the season, resulting in large amounts of water entering the areas to the north of the Delta threatening the town of Old Tokar and being lost to irrigation. Through the construction of suitable "splitter" type structures - as elsewhere - in some key locations, flood flows could be divided between several channels, keeping water volumes manageable and reducing flood impact and also improving the water management.

Improved water management cannot be achieved without good overall land management. This is the main problem in Tokar. With 26 different tribes all operating more or less independently and without forceful overall management, no amount of improved water management will result in substantial sustainable change to the status quo. The attitudes of the government in Port Sudan fail to recognize this and focus on believing that engineering works will solve all. In such a working environment, sustainable solutions will not derive.

(4) Combine spate irrigation with groundwater where possible

Where groundwater is saline - as for instance in the spate-irrigated areas in She'eb in Eritrea - it cannot be used for irrigation, but where water quality is good the combined use of groundwater and spate irrigation can give rise to very productive water resource systems.

In the Gash flood plain in Sudan, groundwater from shallow wells is used along the river for the cultivation of horticultural crops (i.e. bananas and onions)[18]. This has become the foundation of the regional economy and has generated a significant demand for wage labour. Groundwater is also the major source of water for livestock in the tail reach of the Gash irrigation scheme[19]. Reportedly, three groundwater basins are recharged with flood water from the Gash River[20], whereby one branch canal is devoted for the recharge of one groundwater basin. Similarly in the Raya and

Kobo Valleys in Ethiopia groundwater resources are developed at a rapid rate.
In theory the combination of spate irrigation, recharge and groundwater use can combine the best of both worlds - constant fertilization from flood flows, precision agriculture from shallow wells and frequent recharge. This is also a huge opportunity in the Somalia systems. It is also important to understand the sources of recharge - this comes mainly from the riverbeds, yet flows need to controlled so as to infiltrate. The high productivity of groundwater-based irrigation raises the question if the best strategy for the spate water management should be focused on groundwater recharge rather than direct agricultural productivity of spate-irrigated agriculture or where the best equilibrium lies. At present, the relationship between spate diversion and groundwater recharge is generally not well understood. Some studies are undertaken but a solid assessment for instance of the most effective recharge strategy is still missing for any spate system in the world.

(5) Explore new crops

The cropping patterns in spate-irrigated areas in the three Blue Nile countries are currently by and large dominated by the cultivation of low-value, drought-resistant subsistence crops, mainly sorghum and millet. In most spate irrigation schemes, farmers prefer the use of local cultivars as they are well adapted to the local agro-climatic conditions and to local food habits and livestock needs. There is scope - not well explored - for improved main staple varieties. Cotton, hibiscus, pumpkin and melons in limited quantities are also grown as cash crops. In addition, the production of fodder crops to support livestock is also important in several of the spate irrigation systems. The selection of the crop and varieties is mainly determined by the location of the spate irrigation system; the resistance to drought, pests and diseases; fodder production; storage; and market prices.

The yields of spate-irrigated crops vary widely between and within countries and spate irrigation schemes for years with good rains and floods and years with less than normal rainfall. In general yields in spate systems are several factors higher than in rain fed systems. In the Gash Barka (Eritrea,) the average sorghum yield was 1,200 to 2,100 kg/ha in spate-irrigated areas against only 450 kg/ha on rainfed land. In Sheeb sorghum yield fluctuates but in a good year could reach 3750 kg/ha and in some cases even 6000 kg/ha. In Kobo in the northern part of Amhara in Ethiopia, the sorghum yield doubled and the pepper yields were 400% higher with the availability of flood water.

The wide ranges in yields observed in different spate irrigation systems in various countries are attributed to the unreliability of irrigation, availability of additional rainfall, degree of control of spate flows, planting date, sensitivity to inadequate watering, crop husbandry skills, soil moisture conservation practices, crop type as well as attacks by insects and diseases. They also suggest that there is considerable scope for improving productivity.

In improving agricultural production in spate irrigation in the countries of the Horn of Africa there are several routes:

(a) Exploring the introduction of new crops. Some of the bulk crops in spate irrigated areas elsewhere in the world - particularly lentils (chick peas, mung) and oilseeds (castor, sesame, rapeseed and mustard) - are as yet not grown in large numbers in spate areas in the Blue Nile countries, even though they are grown under other conditions, are suitable to cultivation in remote locations and are even part of local food habits. Similarly there may be more scope for bio-fuels and agroforestry plantations than currently explored - for instance under out grower models. More work is required to expand the range of crops and farming models in the spate irrigation systems.

(b) Improving draught animals and mechanization. Ownership of oxen and availability of mechanical equipment is often a constraint. In the Western

18) This has only been possible in areas along the Gash River most of which are illegal settlements because they are contained within the designated protected me and a belt of the river. The concessions had been given to important people I the local political leaders and are therefore reinforcing the elite rather than meeting the needs of the poor people. Ground water away from the course of the Gash River is limited.

19) In addition an important part of the Gash irrigation system is the provision of haffirs at the end of the main canals. Because of the debris and still contained in the first seasonal flushes, the system has been designed to take these flows directly to the haffirs for water is allowed to go on the era dated land. Haffirs therefore have a very important role in the drier parts of the Gash but has suffered from relatively poor designs that have got the depth to area ratio wrong.

20) These were developed either British within areas of deeper tube wells supplying the towns of Aroma, Tendelai etc. These are not recharged by the Gash River directly but by special link canals that serve only these recharge areas. The system works well but is plagued by a lack of maintenance for the link canals. The types of soil within the Gash area away from the Gash River are not conducive to groundwater recharge.

Lowlands of Eritrea and the Gash irrigation scheme, planting of the crops were delayed in many cases due to a high demand for a limited number of available tractors and implements. In Konso in Southern Ethiopia the non-availability of draught animals also affected the construction of diversion structures. The presence of ample draught animals makes it possible to store soil moisture soon after the flood events by timely ploughing and mulching.

(c) Improvements in grain storage. In Eritrea traditional grain storage causes 4-14% crop loss (Haile et al, 2003). Post-harvest losses can be brought close to zero with the use of improved storage methods, such as seed cleaning before storage and the use of storage container, placed away from living places and detached from the floors and walls of houses.

(6) In general strengthening the link with livestock

It is important to strengthen the link with livestock production around spate irrigated areas.
Firstly, as livestock is an integral and important component of the livelihoods of the resident households in most spate-irrigated areas, access to sufficient fodder is crucial. The main source for animal feed is usually crop residue and rainfed grazing lands. A second source is the cultivation of spate-irrigated fodder crops, such as (green) sorghum. In Eritrea, Somalia and Sudan, ratooning sorghum is an important feed for livestock as well. The cutting of weed in the fields and along the canals is another source of forage, whereas leaves from trees in and around the spate-irrigated fields are also used to feed animals. For instance, households in the Sheeb area in Eritrea practice 'zero-grazing' from October to May, whereby the animals are fed with cut grass from the fields, to prevent livestock from causing damage to standing crops and to economise the scarce animal feed. Farmers in the northern part of Amhara State (Ethiopia) also indicated that spate irrigation boosted the availability of animal feed due to a significant increase in biomass production. The improved availability of animal feed has improved household income generated from livestock products.

Secondly the development of spate irrigation should benefit both sedentary farmers and pastoralists. Elsewhere in the world productive symbiotic relationships have developed and the same would need to develop, particularly if spate irrigation is expanded in lowland areas. A potentially important source of fodder is spate-irrigated grazing land. In the Gash flood plains, a large area is covered with a large variety of annual and perennial grasses due to seasonal flooding with excess flood water from the Gash River. According to traditional water governance practices, the first flood in the river would be diverted to the extremes of the scheme in order to stock drinking water for livestock and to irrigate the grazing lands, so that animals would be kept away from the planted crops. However, increased mechanised farming activities in traditional grazing lands as well as the migration of additional livestock herds from other areas have enhanced the pressure on the remaining rangeland, which are gradually deteriorating. Several techniques can increase the productivity of such rangelands - such as flood water spreading, as experience elsewhere shows.
Under the Artificial Groundwater Recharge Project on the Gareh Bygone Plain in Iran, the average yield of indigenous vegetation on spate-irrigated rangeland was 11 times higher (445 kg/ha) than for rainfed land (42 kg/ha), whereas the average crown cover was 31% for spate-irrigated rangeland against 16% for rainfed grazing land. If the yield of the planted quail bush is also added, the overall yield for spate-irrigated rangeland is 23 times higher, which is enough to graze 4 sheep on one hectare during an entire year. Spate irrigation was tried in Turkana district (Kenya) in the late 1980s, aimed at producing pastures for the pastoral communities. This was done through temporary brushwood diversion weirs with graded canals to facilitate the overtopping and even spread of the water. The systems were in principle productive, but were not sustainable since they had been constructed through food for work programs with little community ownership.

(7) Systematic farmer involvement

Spate irrigation development need to be supported by systematic managerial involvement of farmers - in designing and implementing sustainable projects, in management and in provision of additional services such as extension or eradication of invasive species, in particular mesquite.
Particular where there is a farmers tradition of spate irrigation, their knowledge regarding their preferences of the scope and type of works, changes in layout, location of diversion structure, type, alignment and size of off-takes is extremely valuable.

The Eastern Lowland Wadi Development Project provides important and positive learning in this respect. The role of the Sheeb Farmers Association and farmers participation is described in annex 1. There are several lessons of Sheeb - that apply in all spate irrigation development in the area. The first point is that it is good practice to engage in a systematic and representative way an Association from Farmers from an early stage. An early cooperation and partnership will improve the quality of the design concepts as well as the acceptability of the project. In discussing designs it is important to realize the limitations to discussion when entirely new ideas are introduced as was the case in ELWDP. This requires a good understanding on the part of the designers as to what are farmers priorities and experiences with respect to flood capture, sedimentation management and assessing the risk of gully-ing. It also requires that not everything is designed at once and on the drawing table only. One has to avoid that outside engineers norms substitute farmers priorities. The command area works demonstrate how the cooperation between the SFA and ELWDP should work: allowing sufficient time for adjustment and settling of water rights related issues. A second point is to build the Farmers Association on traditional leadership, where possible, particularly where - as in Sheeb - a sophisticated and equitable local organization is in place. The representatives of the local administration may also have a function in the Association, preferably supportive and advisory. A strong feature of the SFA was that membership was compulsory to all farmers of the area: the nature of cooperation in managing and maintaining the spate system is not voluntary. To make the Association work requires time and should be supported by capacity building in both operational (overall system concepts, operation of gates, heavy equipment, gabion works) and managerial aspects (estimating costs, revenue collection, store keeping, record keeping, organizing meeting). Similarly the early introduction of a simple and transparent method of fee collection, as the receipt system that is applied in the SFA, is very useful.

(8) Maintain the bigger picture

A final point in unlocking the potential in spate irrigation is to maintain the bigger picture and avoid a reductionist approach that focuses on the irrigation system in a narrow sense. There is much to gain by the introduction of new crops and better moisture management, as described below. In many spate system drinking water supply is also precarious and living conditions will improve considerably if this issue is improved. In the systems in Sudan land tenure was a particular problem to be addressed. The experience from the gash project shows the importance and impact of securing land titles and also the persistent effort required in doing it. Also in Tokar, there are some 16,000 hectares that are reported to be clear of mesquite in Tokar, but that are still not properly irrigated due to the irregular land surface and also the presence of scrubs, bushes, dunes and others. Establishing a better system of land management - with penalties for non-compliance - is a pre-condition for improving productivity of the system.

4 Conclusions - a research and development agenda

Spate irrigation is still largely unknown - although there is an encouraging interest in it - as seen from new investment programmes in Ethiopia and Eritrea, as well as many examples of farmers investing in new systems. In Sudan the Gash system after decades of neglect was rehabilitated and the same is considered for other systems in the country. The interest is both from investment programming and also from researchers and professionals. The latter is also very welcome as there is still considerable ground to cover in support of the development of spate irrigation - part of this concerns the dissemination of experiences (institutional, engineering, agronomic) from elsewhere; part of it concerns investigations and research particular to the region.

An important need is to better map the areas with potential for spate irrigation in all three countries. It is clear that in Ethiopia, Eritrea and Sudan pressure on resources and the need to make productive use is very high. The story of the Gash system is an illustration of how even in ‘difficult’ areas the number of persons depending on the water and land available has increased and will continue to do so. The same is clear from the movement towards the lowlands in Ethiopia. In many areas spate irrigation is the main route to create higher productivity - particular if combined with groundwater recharge and integrated with the local pastoralist economy. It is important to map the areas where spate irrigation holds promise - existing areas that can be improved and new areas that can be developed. The mapping can be done systematically - looking at the catchments, the run-offs and the agricultural areas. Particularly in many lowland plains there may be unutilized potential. All this would need to be better identified - to start with at reconnaissance level.

A second area for research is in the field of agronomy. As was mentioned several types of crops that do well under comparable conditions elsewhere are not known in Blue Nile Countries. Some fast-track successes may be possible by testing such crops and varieties in Ethiopia, Eritrea and Sudan. The tetron sorghum variety for instance that became very popular in Sheeb in Eritrea was 'discovered' by local farmers visiting the Port Sudan area and then starting to experiment with the variety. Similarly in some areas long-maturing varieties are common, whereas short duration varieties may fit in better with the crop calendar.

A third field for investigation and implementation would be the use of spate development concepts, hitherto unknown in the region: flood spreading, the use of earthen bunds for guiding water on alluvial lowlands, maximized recharge of shallow aquifers underneath spate areas.
A fourth area of research would be to investigate how to support the development of the spate systems - in particular what does it take for farmers to develop or expand their areas. In Weltane for instance the use of the recession flows is fairly recently. The question is what triggered this and what facilitated this; how did local farmers acquire the skills and understanding and how did they cooperate for the first time in making the system happen? How were rights, rules and entitlements settled? In the same vein it is useful to look at the larger government organizations that are supposed to facilitate the development of spate irrigation. Is their knowledge up-to-date and do they appreciate the many facets and the large picture? How will are they equipped financially and with people to support themselves and others to achieve the potential that is imbedded in spate irrigation in the Blue Nile countries.

Annex I Case Study: Review of 'Modernization' of Sheeb Systems, Eritrea

The main route taken to spate irrigation improvement in Sheeb under ELWDP has been that of civil engineering improvements. The engineering concept for ELWFP was first given in the SAR. The work identified in this document was a permanent weir, a breaching bund, a head regulator and a sediment sluice. For cost reasons the headworks should be designed to pass a flood with a 5-year return period. Apart from the developing the headworks, command area improvements are identified. These consisted of improvements to the traditional off-take channels (which need to be connected to the new headworks) and the provision of permanent cross regulators and off-take structures.

The designs were prepared under an international consultancy from 1996-1998. Detailed topographical surveys were made of the wadi head area. Longitudinal and cross-sectional surveys were made of the canal reaches of Wadi Laba. In addition aerial photos were taken in February 1997. Hydrological studies were made, though seriously constrained by the lack of data. As part of these studies a stochastic model of the regional daily rainfall climate was made. Rainfall data from Massawa had to be used, in the absence of data from Sheeb itself. The model was used to assess spate incidence in the wadi catchments. This was then used to generate random peak flow values for the spates. On the basis of peak flows and the available knowledge on spate recession characteristics, hydrographs for discrete spate events were generated. These were then accumulated in flow/volume curves, which indicate the proportion of the total season or year's volume, which arrives in flows under a given value. This was then matched with annual crop water requirements, based on the FAO CropWat program. To arrive at an estimate of the actual volume of water required to be diverted to fulfil the crop water requirements, provisions were made to compensate for assumed gate operation/diversion efficiencies (80%) and canal and field irrigation efficiencies (25%). On the basis of this analysis the diversion capacity for the main gates at Wadi Laba was set at 35 m^3/s. This would divert 87% of the flow in a median year (according to flood/volume graphs) and would make it possible to irrigate an area of 2890 ha. The design of the off-take structures, the sedimentation pond and the command area canals are all based on this figure.

Given the absence of data, a proxy methodology had to be used, but there are a number of observations:

- The methodology by necessity contained several shortcuts. One of these was the use of data from coastal Massawa, which has a different rainfall pattern. Another shortcut concerned the generalized assumptions on diversion and irrigation efficiencies. Similarly the CROPWAT program gave a generic figure for crop water requirements, not taking into account the specific characteristics of local wide-rooted varieties such as hijeri. An assessment of the impact of variations on these parameters on required diversion capacity would have been appropriate.
- The flood/volume graph predicted the total volume of water that arrives in flows under a given size[21]. The graphs did not take specific notice of the sequencing of floods, as many small floods may mean that little water is reaching tail areas. Nor did the method take into account the probability of a year deviating from a median year. By simply using a median year and not taking into account the standard deviation, the size of the gates is set at too conservative a level, using the method chosen.
- In interviews farmers almost without exception made the point that the capacity of the off-take structure is related to the likelihood of the breaching bund breaking. This consideration does not seem reflected in the determination of diversion capacity. On the face of it this is related to the fact that the negative impact of the breaching of the bund (loss of irrigation supplies, rebuilding effort and downstream damage due to flood releases) is not taken into account in the design considerations. An alternative approach could have been to look at the very high flood levels and design the intake of the systems in such a way that such devastative floods would be excluded.
- In general given the absence of data and the variation in floods a much bigger risk margin could have been considered in the design of the system and in particular in setting the size of the gates.

21) From the December 1998 Design Report it is not clear whether the volume for the flood season or for the entire year were taken. In the latter case there is a likely overestimation of water effectively diverted, because floods arriving after September are not always utilized, because the crop is already on the field.

The final designs for the Wadi Laba, Mai Ule and Wadi Labka headworks include a sedimentation pond (or gravel trap) in addition to the off-take gates, scour sluice, weir, breaching bund and link channels, foreseen in the SAR. The sedimentation ponds were added to the design to cope with the large sediment loads of the flood flows. The idea was to trap the coarse sediments at a single point rather than having to clean out long lengths of channel. In principle the scour sluices would take care of the removal of the coarse bed load, but the experience in Yemen was that farmers blocked the scour sluices on most modern structures, to avoid water escaping from the system. To prevent accelerated sedimentation of the channel network sedimentation ponds were therefore added to the design.

Another addition was the 600 meter long culvert in Wadi Laba to route water from the right bank to the left bank command area (Sheeb Kateen). The original concept was to have a separate off-take gate on the right bank. This idea was abandoned because changing bed levels upstream of the headworks moght make it difficult to divide the water properly between the two banks[22]. Finally, in Mai Ule a new flood diversion channel was included to route large floods away from the command area.

The sedimentation ponds and culvert did not feature in the preliminary designs of the SAR and thus increased the cost. Financial estimates further escalated because of the larger safety margin for the head regulators (stronger armouring of the structures) and the change from the originally envisaged force account implementation to international competitive bidding, which required the inclusion of contractor overheads. As the civil works costs had increased significantly, tripartite discussions were held with MOA, engineering consultants and World Bank. Savings identified in these discussions concerned mainly the downstream works where concrete structures substituted the gabion works. When the Wadi Laba and Mai Ule works were finally tendered, the costs for the headworks were USD 3.53 M and USD 2.06 M respectively. This works out to be USD 1420/ ha and USD 2420/ ha respectively[23]. This may be benchmarked with other recent engineering investments in spate irrigation. Engineer's estimates for spate irrigation systems prepared in 1996-2001 in Balochistan (Pakistan) are USD 646/ha (Nal Dat), USD 1346/ha (Marufzai) and USD1478/ ha (Barag). The cost for Barquqa in Yemen is USD 1507/ ha originally (but increased substantially subsequently to over USD 9000/ha). The Wadi Laba costs are then in the same league. Mai Ule, however, is relatively more expensive. Moreover, because the catchment of Mai Ule is considerably smaller and entirely located in the lowland zone, the reliability of irrigation in Mai Ule is less. The economic feasibility of Mai Ule is therefore more problematic. The estimate for all works at Wadi Labka was USD 8.50 M or USD 3517/ha. This was beyond the budget of the project and the work at Wadi Labka in the end was dropped. The proposed works at Wadi Labka were moreover complicated because of the difficulty of supplying the left bank.

Performance

The headworks and the link canals were constructed between 2000 and 2002. In this section a brief assessment is made of the performance of the system in the first (unusual) year and the subsequent years and brief outlook on its future sustainability is given.

Several delegations of farmers requested that the designs be adjusted at this stage - in particular increasing the size of the off-take gates. There was discussion and fact-finding with farmers during the design stage, but the traditional farmer organization was not systematically involved nor prepared for a future role in operation and maintenance. Given the strength of the traditional organization of *ternafi* and *teshkils* it appears this was a missed opportunity.

No attempt was made to reach mutual agreement whilst designs were being prepared. During the construction stage modifications were not considered either, partly because major redesign - such as a larger off take capacity - at this point would have been difficult to accommodate and partly because communication and mutual understanding remained inadequate. Farmer involvement however improved towards the latter part of the project under the irrigation management transfer and CAD subcomponents.

First year of performance

Soon after completion the Wadi Laba and Mai Ule modernized systems were put to a severe test. On 30 August 2002 an unusually high flood arrived after heavy rainfall both in the catchment

22) In retrospect this issue could have been resolved by farmers constructed minor traditional division strucutures upstream of the weir.

23) The costs are USD 1650/ha for Wadi Laba and USD 3094/ha for Mai Ule, if costs of design and supervision are added.

of Wadi Laba and Mai Ule. Particularly in Mai Ule this flood was assessed as being larger than any witnessed in living memory[24]. The damage caused by these large floods was considerable. Most damage was to the canal and flood embankments, the link canals and the spurs in the river. The Mensheeb link canal was largely destroyed. The Errem and Mensheeb cross regulators were severely damaged. The lower part of the Mai Ule diversion canal was also washed away. The 'hard' structures on the other hand suffered relatively little damage. The total bill for emergency repairs was USD 507 000.

An assessment fielded soon after the flood event, attributed the damage not only to the extreme flood but also to a number of other factors:

- The delayed breaching of the breaching bunds in both Wadi Laba and Mai Ule. Instead of breaking on the rising floods the bunds only gave way at the receding limb of the flood by which time the Mai Ule headworks had started to overtop and the Wadi Laba headworks nearly overtopped. The assessment notes that "the specifications of the breaching bund were inconsistent with the breaching requirements and the time for the breach to occur". The compaction of the bunds was too strong and comparable to the compaction of flood embankments (which are not supposed to breach).
- The off-take gates being open throughout the floods and the scour sluice being closed at the same time - releasing large part of the flood flow through the channel network. Gate closing was further complicated because of the operational difficulty of closing the gates in time and the fact that the operators left the area in fear of their lives.
- Insufficient compaction of the silty material near the regulators causing piping
- The gravel trap already being filled with sediment prior to the flood events, so that no sediment carried by the floodwater could be trapped. The gravel trap was filled with sediment because regular cleaning is a difficult task.
- The limited capacity of the diversion canal in Mai Ule particularly in the lower reach, making it impossible to divert the full flood flow.

The damage caused by the August flood had a considerable impact on the confidence of farmers in the appropriateness of the new system. The main complaint is that with the breaching bund floodwater builds up and upon its breaking the water is suddenly released, doing considerable damage downstream. Farmers also make a connection between the breaking of the bund to the overall small size of the gates - which does not allow the floods to be channelled to the system in time. The observation in section 5.1 suggests that these points are valid. Farmers compared this with the traditional system where big floods are spread evenly over the wadi. Even though such big floods break the agims and cause erosion in the command area, part of the water still utilized. In other words the new systems performed worse in capturing part of the big floods.

Subsequent years

After the exceptional August 2002 flood a successful accelerated effort was made to restore the flood damage and ensure that the opportunities for spate irrigation in 2003/2004 would not be lost too. The 2003/2004 year was, particularly in Wadi Laba, a 'good' year with 28 floods up to the end of the flood season and 13 more in September-December. Similarly 2004 and 2005 were good years in Wadi Laba with 15 floods in 2004 (mainly medium and large floods) and 39 floods in 2005. In all these three years the area under cultivation has been slightly above 80% of the total area in Wadi Laba. In Mai Ule it was considerably less (20-30%) in 2003 and 2004, but coverage in 2005 also touched 80%.

The 2003-2005 seasons make it possible to review the operation of the system under normal conditions. One major issue has been that the breaching bunds have been breaking far more frequently than the once in five years that was anticipated. The breaching bund in Wadi Laba broke once in 2004 and once in 2005. The Mai Ule bund failed 2-3 times every year, in this case effectively loosing half of the medium and large floods in Mai Ule. In two cases the breaching was related to gatekeepers not opening the gates, in other cases the flood was high, but not extreme. In Mai Ule the frequent breaching seems related to the angle and narrow section at which the water approaches the bund. In both Mai Ule and Wadi Laba it has not been possible to restore the breaching bund from the upstream section, because the soil was saturated and could not sustain bulldozer operations. Instead the bunds were constructed from the downstream part of the

24) In Wadi Laba and Mai Ule the flood is perceived by farmers as larger than any other floods in the last five years, but not exceptionally large.

river bed where the material is more coarse.

The cleaning of the gravel trap also presents a problem. The trap fills after a limited number of floods and that with fine sediment, not by gravel[25]. The idea was that the pond would be continually cleaned out with the bulldozer, but the bulldozer had difficulty accessing the gravel trap and working in the saturated fine sediment. In the course of the project the gravel trap was cleaned three times only with the use of excavator and bulldozer at high costs (nearly USD 40,000 each time). One can ask questions as to the added value of the gravel trap. Most of the sediment trapped consisted of relatively fine material rather than the coarse gravel that the pond was supposed to intercept. This fine material, that is intercepted, is appreciated by farmers to build up land, manipulate channel sedimentation and add fertility and they do not like to see it lost. The design of the gravel trap is also such that when small floods would come just after cleaning the gravel trap that these smaller floods 'fall' inside the gravel trap and are not released from them. It is questionable whether the gravel trap serves any useful function under these circumstances.

The Sheeb Kateen culvert has also not functioned as envisaged. Very little water has passed through the culvert. One of the two barrels of the culvert is solidly blocked. There are a number of explanations for the performance of the culvert. The first is that at the outlet of the culvert there insufficient head, causing the silt to accumlate upwards. Next smaller floods carrying considerable sediment loads cannot pass through the culvert, which is designed to be flushed by medium and larger floods. Once silt starts to accumulate, the sedimentation of the culvert may block smaller floods that cannot lift the sediment deposited by the previous flood. Another factor is that the culvert opening is at a straight angle to the flow in the gravel trap. Even though the opening of culvert is 8/27 of the downstream overflow to the left bank area, it may not get this proportion of flood water, particularly if the silted up gravel trap starts functioning as a channel.

Farmers have compensated some of these shortcomings by adjustments to the system, initiated by the SFA and the local administration. A hybrid modern-traditional system in fact developed. The adjustments mainly concerned the capture of run-away water (from breaching of the bunds; overtopping of the weir crest or releases through the scour sluice). Three of the main modifications are:

- The Agim Tzegai immediately downstream of the Wadi Laba headworks, diverting water from the scour sluice to Sheeb Katin area - compensating for the limited effectiveness of the She'eb Katin culvert. The She'eb Katin farmers have also requested and been allowed to use water from the scour sluice at medium floods.
- The agim at Tsewra that diverts floods from Wadi Laba into the IdeAbay command area. This is an old agim, that in the original design would have become redundant by the Wadi Laba headworks and the Mensheeb link canal, but continues to be used and has been reinforced.
- The new intake downstream of Mai Ule headworks, where water is diverted through a cut in the embankment works, whereas a bund has been constructed across the main river.

These adjustments have helped to avoid water getting lost from the Sheeb area. However, particularly the new Mai Ule intake and the Tsewra agim can bring substantial erosion to their command areas, because they can direct large and potentially devastating floods to these areas as well. The design of these modifications may be relooked for options that reduce unnecessary risk.

Sustainability

The main question with respect to the sustainability of the Sheeb systems is the capacity of the Sheeb Farmers Association to maintain the diversion structures. The Sheeb Farmers Association was established in January 2004. The first transfer agreement was signed on 28 February 2004. Its constitution was ratified in November 2004. The Sheeb Farmers Association is the first of its kind in Eritrea. It is officially recognized by the Ministry of Agriculture and the Zoba Administration.

The structure of the SFA is modelled on the traditional leadership in the spate system. As discussed prior to the SFA work on the spate system in each of the seven sub command areas (*partas*) was coordinated by local leaders, i.e. *ternafis* (2-3 for each *parta*). The work was organized through *teshkils* consisting of approximately 20 farmers each. To this traditional structure the SFA added a

25) Originally the sedimentation pond was designed on the assumption that the scour sluice would not be effective in sediment control. The development of new traditional downstream off-takes (at Sheeb Kateen and Ide Abay) however ensures that there is a vested interest not to close the scour sluice. Most of the coarse bed load may be removed through the sluice rather than trapped in the pond.

superstructure, i.e. an Executive Committee that has taken charge of the management of the entire Sheeb Spate System, both in Wadi Laba and Mai Ule. The Executive Committee is answerable to the General Meeting of all members, which convenes once a year. The Executive Committee consists of seven members, i.e. Chairperson, Secretary, Treasurer and four members . The four members look after the irrigation works.
As in the pre-project situation, the SFA works through 22 *ternafis*, three for each of the seven main *partas* and one for the small *parta* of Kirfotat.

The main objective of the SFA is to ensure the efficient operation and maintenance of the irrigation system, so that the members can make full use of the spate irrigation development. Secondary objectives are that members pay the annual fees for the system objectives, to properly manage the funds of the Association, liase with government, mediate in disputes between members and ensure adequate communication. Given the fact that it has been existence for only two years, progress of the SFA is very considerable.

Some points:

- It is now raising annual fees (Nfk 500/ha) up to the full level of maintenance requirements of the ELWDP works;
- In addition it is coordinating maintenance and repairs on other (traditional) structures. The monetary value of these works are of a similar order of magnitude, as the ELWDP maintenance works;
- It has coordinated adjustments to the Wadi Laba and Mai Ule spate system, that accommodate the new situation that has arisen with the new infrastructure. In particular it has settled changes in water distribution between the various subcommands (*partas*);
- The SFA encourages richer farmers to support poor farmers by having them use the bullocks to prepare land;
- In general, the SFA and its decisions are well-known throughout the area.

Annex II

Table 3 Engineering Structures in Spate Irrigation

Summary Overview of Options and Issues		
Category	**Structure**	**Notes**
Diversion	Weirs	- Create additional head and stabilizes the river bed - but siltation in front of the weir is almost inevitable - and small earthen/ gravel/ brushwood structures are often required in the end. - Cut off weirs should be provided with weepholes as they may interfere with the subsurface flows.
	Flow dividers	- Useful to keep flows in manageable proportions - need enough protection (for instance with aslar) to avoid damage.
	Deflection spurs	- Common higher up the river/ gravel fans - Catches parts of the flood - and in case of high flood can be overtopped and exclude the large flood
	Gravel dykes	- Suitable to divert flows towards intakes and can be alternative for permanent weirs (but need rebuilding) - Reinforcement with gabions or abutments - Often at angle
	Soil dykes	- Suitable in lowland alluvial spate systems: low cost - Location and choice of material is important (silty-loamy, non-saline) - Reinforcement by gabions, plastic sheets, brushwood or pegs - Often build at angle
	Conical abutments	- Can protect intakes or heads of spurs and stabilize soil bunds
	Breaching bunds	- Will act as 'fuse plugs' and break and allow large floods to pass and save main infrastructure and command area - Avoid having breaching bund high up the gravel fan as they may break too fast - proper location is in plain areas.
Intakes	Multiple intakes (and short canals)	- Preferred so as to minimize conflicts and management problems
	Open intakes	- Large dimension - so as to pass large volume of flood water in short time - Curved wing-walls preferred
	Orifice intakes	- Will make it possible to exclude unwanted large floods
	Gated intakes	- Can allow closure of area if it - Mechanical operation may be difficult and mechanical operation is expensive
	Rejection spilways	- Allows rejection of destructive floods
	Scour sluices (preferably with curved skimming weir)	- Can work but are often closed by farmers as they do not want to loose water
	Sedimentation ponds	- In most these do not work - as cleaning and flushing is cumbersome and farmers do not want to 'spend' water on this
	Trash racks	- Put at angle so trash is guided to main river - Need provision to clean as large trash catches smaller trash

Table 3 Engineering Structures in Spate Irrigation (continued)

Summary Overview of Options and Issues		
Category	**Structure**	**Notes**
Canals and command area structures	Steep channels	- Preferred in upstream areas with heavy sediment load to carry fine sediment all the way to fields (for slope look at natural drains)
	Shallow wide channels	- Effective in dissipating energy - In general try to avoid drop structures - can sometimes different channel route
	Stepped drop structures	- Effective in dissipating energy - In general try to avoid drop structures - can sometimes different channel route
	Gabion flow division/ diversion structures	- Ensure that downstream apron of gabion structure is long enough to avoid back cutting - Can stabilize the bed of the flood channel
Field structures	Improved field intakes	- Allows closure of field after it is filled with water
	Overflow structures	- Useful if there is level difference between to prevent uncontrolled gullying in downstream field
Groundwater management	Low recharge weirs	- Will reduce velocity of flows and induce recharge

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Overview Paper #2

Colofon

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The Spate Irrigation Network supports and promotes appropriate programmes and policies in spate irrigation, exchanges information on the improvement of livelihoods through a range of interventions, assists in educational development and supports in the implementation and start-up of projects in spate irrigation. For more information: www.spate-irrigation.org.

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