29

Improvements in the Design of Flood Diversion Structures

Practical Note

Flood-Based Livelihoods Network Foundation

Executive summary

In spite of being the eldest practiced and widely expanding, spate systems are suffering from technical design problems of flood diversion and distribution, which is not yet resolved. Until recently, efforts to properly understand and improve spate system designs have been limited meaning little is known about the hydrologic, hydraulic and morphologic functioning of spate systems. Relatively sophisticated and costly diversion structures have been introduced to modernize and improve the performance of the systems. These modernizations only resolved the problems associated with frequent reconstruction and maintenance of intakes.

The main objective of the study is therefore, to introduce a new design approach which is sustainable and that optimize the benefits of both the traditional and modern systems without affecting the existing traditional institutional setup of the systems. This study was conducted using the Oda and Mersa Spate Irrigation Systems located in Raya Alamata, Ethiopia. The study has used qualitative and quantitative methods to determine key parameters. It also involved 35 farmers from the 17 spate systems of the valley and 4 experts from the two districts (Alamata and Raya Azebo Weredas). Furthermore, interviews and consultations were also conducted with senior professionals from relevant stake holders. Detailed topographic surveying along with field observations and walk-through were also done.

These schemes are systematically designed to be a hybrid of the traditional and modern practice, which due adopt, contemplate and optimize the good aspects of both practices. The design diverted discharge is chosen with probability of non-exceedance of 75 % and 50 % for Mersa and Oda respectively. As a result, these schemes can irrigate more than 400 ha each. The overall irrigation efficiency evaluation indicates that, there is 9 % efficiency in the previously constructed spate systems, 84 % efficiency within the hybrid systems and an overall efficiency of 25 %. Finally, some of the failures of FBFS are due to lack of awareness in the differences between conventional and FBFS. Continuous capacity building especially in design aspects should be the key to the development of FBFS.

1. Introduction

Spate irrigation, being a floodwater harvesting and management system, has provided a livelihood to about 13 million resource-poor farmers in over twenty countries for the past 70 centuries (Mehari Haile et al., 2010). Spate systems are constructed with the aim to divert flood flows to irrigated fields through diversion intakes. The diversion structures have to ensure an adequate diversion of highly variable flood discharges to irrigated fields by stabilizing the seasonal river bed and raising the water level. The range of structures comprises traditional diversion intakes (deflecting spurs and diversion bund intakes), improved intakes and modern (permanent) diversion intakes (Lawrence P. and Van Steenbergen F., 2005). The diversion structures need to prevent large uncontrolled flows from entering canals, to minimize damage to channels and field systems and limit the entry of very high concentrations of coarse sediments that are carried especially in the larger floods (Van Steenbergen et al., 2010).

Spate irrigation systems have been practiced for millennia, but it is only recently that the systems have received due attention from irrigation professionals and practitioners. In 2004, the Spate Irrigation Network and partners embarked on evidence-based documentation of traditional and modern spate irrigation systems. This endeavour, which is still on-going, has identified a number of design pitfalls and several practical improvement options to better divert and distribute sediment-laden spate flows.

This Practical Note takes stock of the experiences and lessons learned on design aspects of spate irrigation systems in the past two decades. It then discusses findings of practical research conducted in Ethiopia and zooms into the improved hybrid (combination of traditional and modern) design of the Oda and Mersa spate schemes in Northern Ethiopia's Alamata district. The scope of this Practical Note is limited to the design of intakes and canals. On-farm flood distribution and management structures are not discussed, as these are elaborated in Practical Note 4 entitled "Command Area Improvement and Soil Moisture Conservation" [1].

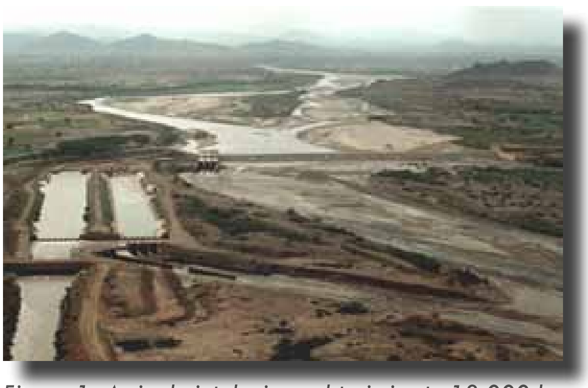


Figure 1: A single intake is used to irrigate 18,000 ha of Yemen's Wadi Mawr scheme (Source: Mehari Haile et al., 2005)

2. Spate irrigation engineering: experiences gathered and lessons learned

Over the past decades, many efforts have been undertaken to improve and modernize the design of the diversion and canal structures of spate irrigation systems. Experiences have been gathered from a diversity of countries, including Afghanistan, Eritrea, Ethiopia, Iran, Morocco, Pakistan, Tunisia and Yemen, and are documented in the Guidelines for Spate Irrigation (Van Steenbergen et al., 2010), the Engineering Manual for Spate Irrigation (Ratsey, 2011), several recent journal articles (Gebehiwot et al., 2015; Zenebe et al., 2015), as well as technical reports, training modules and case studies (www.spate-irrigation.org). A summary of the experiences and lessons learned that are relevant to intake and canal engineering and hence to this Practical Note is given below.

2.1 Vulnerability of hydrological analyses and superiority of multiple over single intakes

In the past, spate irrigation modernisation has focused on heavy engineering dominated by one or at most two concrete main intakes and supply canals. Better control and optimum diversion of floods at the lowest cost possible were the main reasons for a preference for just a single intake. As costs increase with intake flow capacity, flow-rating and flow duration curves were used to avoid over diversion.

This approach has had major drawbacks. The hydrological analysis on which these flood curves are based has not been accurate. Practical experiences have shown that flood return periods used in the design of spate irrigation systems were grossly inaccurate. Some examples: the five-year design floods in the Wadi Laba (Eritrea) and Wadi Zabid (Yemen) schemes have in reality occurred on an annual basis and in some cases, twice a year. The consequence was that the earthen-bund that was supposed to breach only once every five years was overtopped at least once a year. As

1) *http://spate-irrigation.org/resource-documents/practical-notes/*

a result, the intakes divert less flood than their design capacity. The farmers tend to look upon any flow passing the intake and going downstream as a lost resource. This is less of an issue where there are multiple intakes that harness floods at several locations directly from the wadi. The main lesson here is that spate flow hydrological analysis is too difficult to be calculated accurately. Hence, reliance on a single intake is not a good option for the future.

2.2 Wider and shallow canals excel in sediment and flow management

The sediment concentration in spate flows ranges between 4 - 10 %, which is substantially higher than the 0.02 - 0.05 % in most perennial rivers (Mehari Haile, 2007). Traditional spate canals have largely managed sediments because they are usually relatively wide and shallow. Sediment deposition in the bed has a limited impact on the flow capacity and can be easily compensated for by raising the banks. On the other hand, engineered canals are usually narrower and deposition of the same volume of sediment results in a substantial reduction in the flow capacity. Furthermore, shallow canals are hydraulically inefficient as well, which means that they can naturally dissipate sufficient energy to main suitable velocities on relatively steep slopes without any drop structures (Rastey, 2011).

2.3 Scour sluice and drop structure are ineffective, steep slopes are unavoidable

Scour sluice gates and drop structures have been successfully used to control sedimentation problems at intakes and canals of perennial systems. In the absence of sufficiently steep slopes however, their benefits in spate systems have been largely undone by excessively large sediment concentration of spate flows. Many drop structures have become redundant (figure 2); sour sluice gates, even when they are 1.5 m deeper than the irrigation gates, have been subject to siltation. In gravelly river beds, they are often blocked by large boulders (figure 3). Making the structures wider would deprive them from the high velocity they need to generate to discharge coarse sediment-laden floodwater back into the wadi. Another limitation is that farmers often intentionally close scour sluice gates as they do not want to lose floodwater (figure 4).

Coming to the slope, conventional engineering literature advices a bed slope of 0.05 % to avoid erosion, but several experiences as well as action research undertaken in Sudan (Zenebe et al, 2015) and Yemen (Ratsey, 2011) have established that minimum slopes of 0.1 and 0.2 % are respectively needed to avoid significant sediment deposition at the intakes and in the canals. Slope is not the only factor, velocity and discharge also determine whether sediments have to settle or be transported to the command area. With wide range of discharge changes, which is common in most spate systems, there could be sediment deposition or erosion of the canal bed for the same canal route.

Figure 5 graphically displays the impact of slope on sediment management.

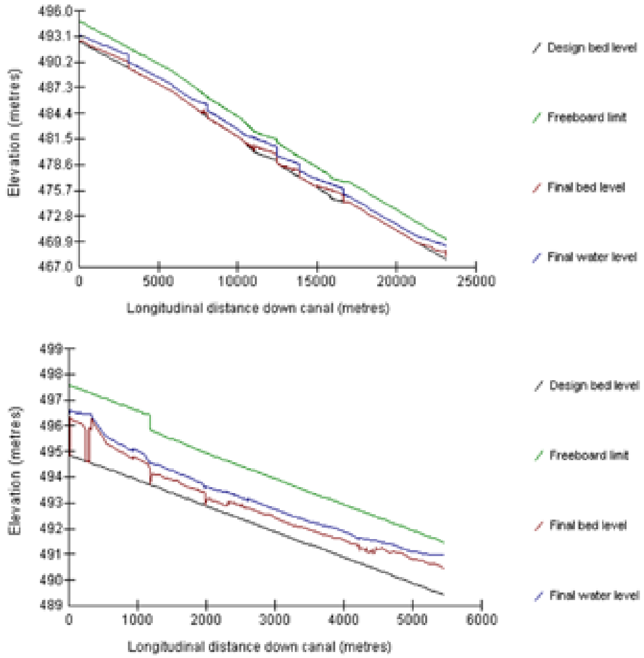
2.4 Right angled intakes perform poorly and are not recommended

The widely-referred FAO 2002 Irrigation Design Manual (Vol. 2, Module 7, Fig. 39) specifically recommends right angled intakes for silt-laden rivers. This manual was, however, prepared for conventional irrigation systems and may not have taken into account large sediment concentrations that are typical for spate flows. Several physical and numerical models as well as field experience demonstrate that frontal intakes divert the minimum of bed load to canals whereas in right angled intakes, the bottom flow carrying the bed load turns the core more easily and there is an increase in the amount of sediment entering the canal (Zenebe et al., 2015; Gebrehiwot et al., 2015).

Figure 2: Farmers intentionally blocked scour sluice gate with gabions (Libsekal et al., 2014)

Figure 3: Large boulders blocked scour sluice gate (Libsekal et al., 2014)

Figure 4: Huge sedimentation made drop structure redundant (Ratsey, 2011)



Aselam Wealkum intake operating at 0.1 % slope – almost no sediment deposition – see the design bed level (bottom line) and final bed level (red line)

Fota intake operating at 0.045 % slope and suffering from huge sedimentation problems. 1.5 m sediment deposition was recorded in 2015

Figure 5: Comparing sedimentation at two neighbouring intakes in Sudan's Gash scheme (Source: Zenebe et al., 2015)

Farmers seem to have long realised the problem as many traditional intakes are frontal and range from 120⁰ to 150⁰.

In Ethiopia, as was the case in for instance Yemen and Pakistan, modernisation and improvement interventions in spate irrigation systems have experienced failures. Among the main reasons is the application of conventional irrigation design approaches and practices that are not informed by the above outlined knowledge and related experiences that respond to the high level of uncertainty related to floods, the hydraulic challenge of guiding flood flows, the heavy sediment loads, and the exceptional nature of water rights specific to spate irrigation systems. According to Eyasu et al. (2011) out of the 17 spate schemes modernized in the Raya Valley, in the Tigray region, 13 have almost completely failed and only four are performing at 50 % of the design capacity.

3. Interventions for improved spate irrigation design in Ethiopia

3.1 Hybrid flood diversion and distribution systems

Supported with action research, substantial improvements to the design were made over the past decade to accommodate the specific characteristics of spate irrigation systems in Ethiopia's Tigray region. The improvements mainly focus on the following:

- Changing the offtakes from closed to open and the diversion angle from 90⁰ to 135⁰;
- Enlarging the canal size and avoiding crossing structures that require pipes;
- Calculating crop water requirement for four hours of daily application and neglecting the effective rainfall. Floods are characterized by short duration and rarely last for more

Events	2002 & before	2004	2005	2006	Since 2014
Off take type	Closed conduit gate	Closed rectangular gate	Open rectangular gate (3m)	Open rectangular gate (3m)	Hybrid design - Open trapezoidal gate (2 - 25 m)
Diversion angle	90⁰	90⁰	120⁰	120⁰	135⁰
Designed capacity (ha)	400	400	500	300	345 (average from 3 schemes)
Actual capacity (ha)	0	0	100 - 150	150	290 (average from 3 schemes)

Figure 6: Historic overview of the development of spate systems in Tigray, Ethiopia

Table 1: Nature of the hybrid spate system

S.no	Traditional	Modern
1	Open and wide intake (2 - 25 m) – maximum possible diversion of floods	Divert only the required amount of small and large floods
2	0.2 - 0.6 m high depending on the size of the opening	Diversion ratio based on demand (5 % at peak flood and 100 % when it recedes)
3	Oriented at 45⁰ or 135⁰ diversion angle	Robust structure – cut-off and apron, river protection structures
4	Causing only small disturbance to natural flow conditions	Hydraulically controlled sediment removal
5	The principle of diverting the flood at multiple locations is exercised	

than four hours. Rainfall is highly erratic to be considered;

- Limiting the irrigation system design to only provision by the main canal.

Figure 6 shows the historic evolution of the intake angle, going from 90⁰ to 120⁰. Coupled with the replacement of closed and narrow (0.8 - 1 m) conduit gates by open wide (3 m) gates it has resulted in substantial improvements. However, the actual performance has remained well below the design capacity. In 2014, a hybrid design approach was introduced that harnesses recent experiences and further integrates traditional and modern know-how as summarized in table 1. Further details on improved approaches and techniques employed for the hybrid design are given in the following section.

The design of hybrid flood diversion and distribution structures and their piloting in the Oda and Mersa spate schemes in the Tigray region was supported by the Africa to Asia: Testing Adaptation in Flood-based Farming Systems (FBFS) and the Participatory Small-scale Irrigation Development (PASIDP) projects. Both FBFS and PASIDP are funded by IFAD. FBFS is implemented by a consortium composed of MetaMeta, Spate Irrigation Network Foundation and ICRAF, with Mekelle University being the key local implementing partner in Ethiopia.

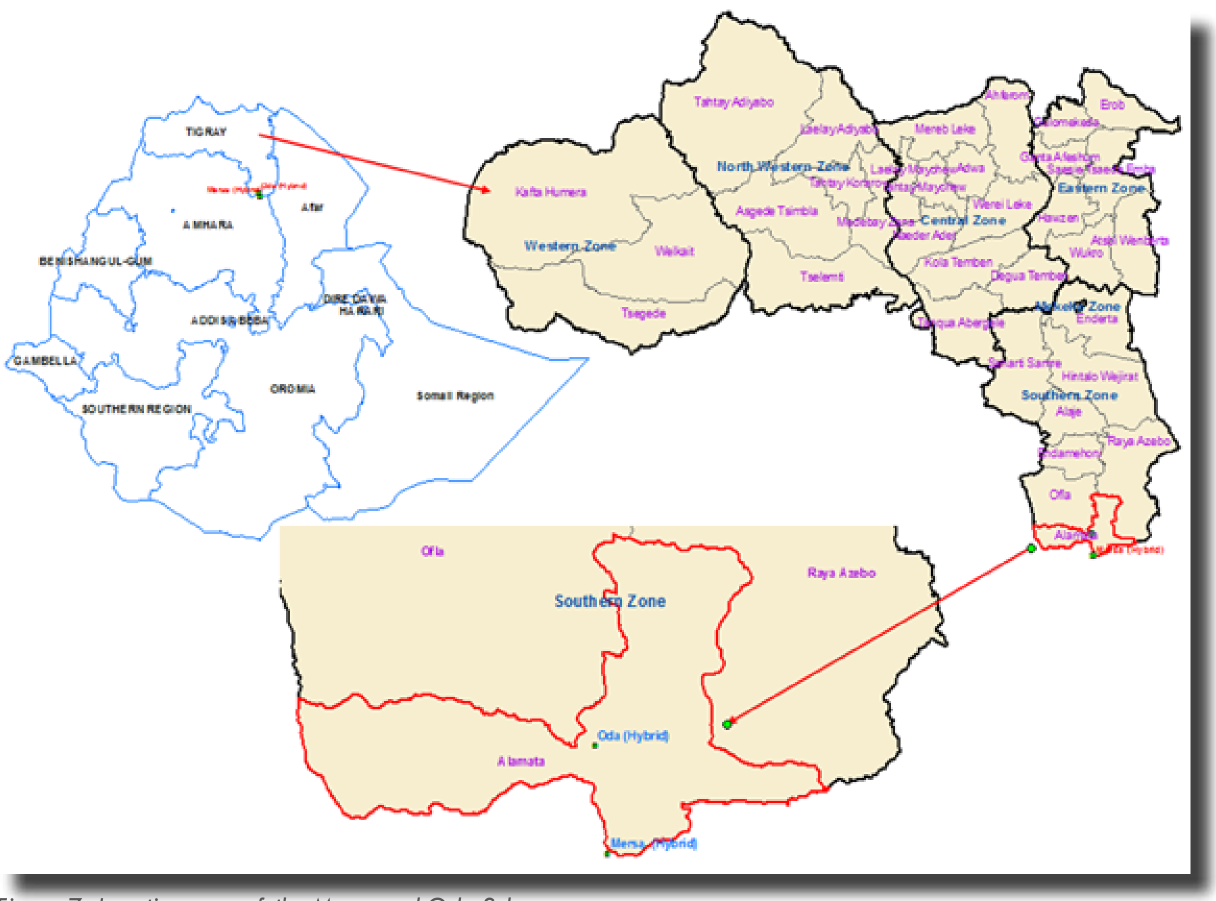


Figure 7: Location map of the Mersa and Oda Schemes

Pilot impact areas

The Oda and Mersa spate irrigation systems are located in the Alamata district of Northern Ethiopia, in an area known as the Raya Valley. The watersheds that feed both spate irrigation systems have a size of 66.6 and 117.6 km^2 respectively. The two wadis are ephemeral with flows occurring during the main rainfall season from June to August, and slowly recede after the rainy season from September to January. With average rainfall in the lowlands of the Raya Valley being around 500 mm per annum but very erratic both in its temporal and aerial distribution, it is not enough to grow crops unless rainfall is supplemented with flood waters that are generated in the highlands where the average rainfall is more than 1,000 mm per annum. Facilitated by this extended flow, farmers with access to the schemes are able to cultivate and harvest their lands twice a year. The irrigation capacity of the Oda and Mersa schemes is 420 and 430 ha respectively.

The study areas are known for their traditional experience with the use of spate flows. In both schemes, floods are diverted into both sides of the wadi, and are distributed on an alternate basis between irrigators on the left and right side, using alternate day shifts. These schemes have well-established and functioning traditional water user associations that enable farmers to harness the floods very well. Besides dividing the water, these associations are also responsible to handle the overall operation and maintenance, resolve conflicts and set turns within the irrigated fields.

Methodology

The design process used both qualitative and quantitative methods to determine key parameters. A literature review was done to track findings in the spate irrigation field. To ensure the participation of farmers and key stakeholders, a focus group discussion was organised that involved more than 35 farmers from the 17 spate systems in the valley, as well as four experts from the Alamata and Raya Azebo districts. Furthermore, interviews and consultations were conducted with farmers and senior professionals from key institutions, to identify challenges related to the design of the spate systems. To ensure that adequate and reliable data was obtained, detailed topographic surveys and field observations were conducted.

3.2 Major improvements in the hybrid design

The resulting improvement in the hybrid design covered the hydrology (determination of diverted flood hydrographs), the design of diversion structures (offtakes), design of the canal system and the determination of the command area. The details are described below.

Design discharge

The design discharge is a determining parameter in the design of the intakes and canals. This is defined as the maximum flood that need to be diverted from a given diversion site to meet the peak irrigation demand. Since both Oda and Mersa have no hydraulic/hydrodynamic gauging stations in the wadi nor meteorological stations within their catchments, the hydrological analysis of the offtake design was done using rainfall runoff spreadsheet models. This is known as the soil conservation services method, which integrates rainfall measurements with catchment characteristics. Accordingly, data from the Korem meteorological station (figure 8), which is the nearest highland station to the schemes, was transferred to the catchment and used to generate peak flood design hydrographs. The station is located at 30 km from Oda and 42 km from Mersa, and has around 40 years of rainfall record data.

The design diverted discharge is chosen with a probability of non-exceedance of 75 % for Mersa and 50 % for Oda, meaning that the probability of diverting the computed discharge or less is 0.75 and 0.5. This data is useful to design an optimum canal. The probabilities of diversion may differ, considering the size of the catchment area and runoff generated. The design diverted discharge will equally be divided to the number of existing major offtakes to determine the capacity of a single offtake and canal. As a result, each of the three offtakes in the Mersa spate system and two offtakes in the Oda spate system have

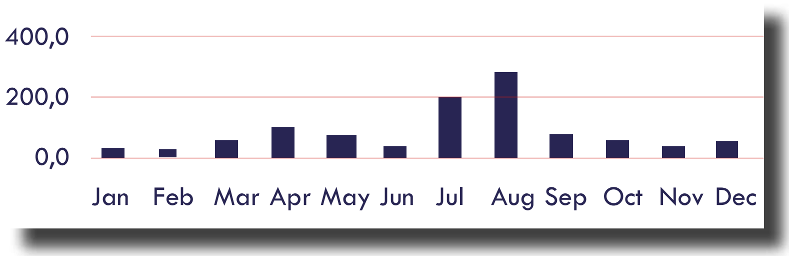


Figure 8: Monthly distribution of rainfall at the Korem station (Source: National Meterological Agency of Ethiopia (NMA))

been designed to divert a flood of 5.14 m^3/s and 4.4 m^3/s respectively. The 75 % and 50 % non-exceedance rainfalls were calculated using SMADA 6 software.

Figure 9 shows that, the peak design diverted flow hydrographs of the two spate systems (Oda and Mersa) for different durations (the peak flow is the cumulative of flows for different durations). These hydrographs are generated bsed on 75 or 50 % exceedence point rainfalls.

To safely accommodate the required discharge into the main irrigation canal, as obtained using the manning equation, the offtakes need to be raised at least by 0.2 m. The manning equation is the most commonly employed equation to analyze open channel flows. Figure 10 shows measurements taken by mini diver installed in the Oda River. From this it can be derived that the 75 % and 50 % non-exceedance floods can be easily obtained. The flood can reach as much as 50 m^3/s in 9.5 hours of time and the required flood to be diverted is 8.8 m^3/s in 10 hours which can easily be attained during the small flood events.

3.3 Design of diversion structures (offtake)

The design of the Oda and Mersa schemes was undertaken using a new approach that draws from the experiences taken and lessons learned through the evidence-based documentation initiative led by the Spate Irrigation Network, the site-specific quantitative and qualitative research conducted as part of the FBFS project in Oda and Mersa, as well as another research conducted in 17 modern structures, funded by NUFFIC under the University Water Sector Partnership Project. These schemes are designed to be a hybrid of traditional and modern systems, incorporating good aspects of both practices. Table 1 has the details, while the schematic layout is as shown in figure 11.

With regard to sedimentation, hybrid design performs better due to the combined contribution

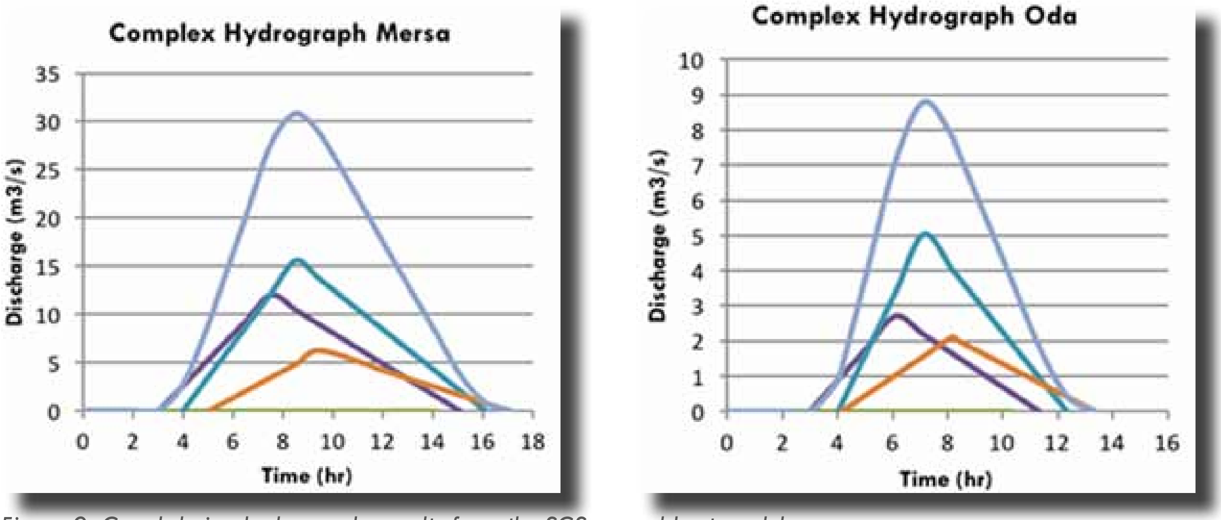


Figure 9: Canal design hydrographs results from the SCS spreadsheet model

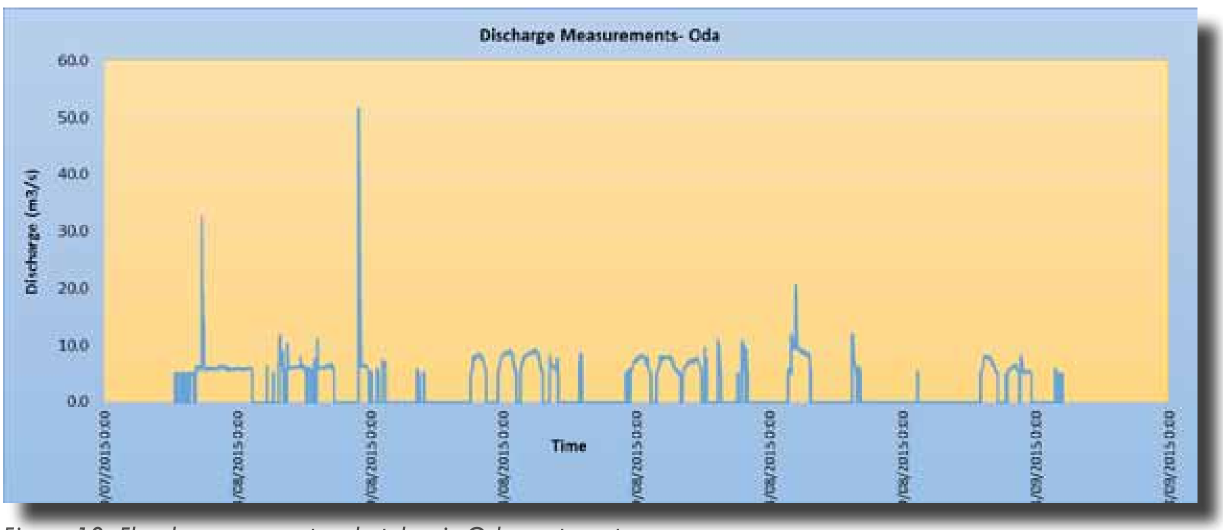


Figure 10: Flood measurement undertaken in Oda spate system

of frontal and wide intakes, the wide and shallow canals and the presence of multiple intakes. The use of multiple intakes has also enabled limiting the capacity of the design discharge in such a way that diversion of large floods that carry high sediment are excluded.

3.4 Canal systems

In most cases, the layout of the drainage and irrigation system route is selected based on the topographic conditions and soil type of the command area. In addition, local experience and farmers' wisdom is crucial to select the canal route. According to Eyasu et al. (2011), the secret to the success of traditional schemes is related to site selection and construction where farmers have developed the necessary knowledge and skills on where to place and design durable diversion structures and canals. The major requirements for designing an irrigation and drainage lay-out are:

- The system follows a route that reduces the need for excavation and fill volumes, by selecting appropriate slopes for the canal that maximize the natural ground slope as much as possible;
- If possible, the canal is made short and avoids areas where construction is difficult and dangerous in respect to economy and safety.

In these systems, only the main canals are considered during the design period. This is mainly because farmers are not willing to construct secondary, tertiary and field canals mainly because these canal networks have forced them not to exercise their traditional water distribution systems, rules and regulations. Nor are they interested to deliver drainage networks.

Two types of canals are used in these systems, namely reinforced concrete and earthen lined canals. Earthen canals are used to minimize costs in places where the bed and side slopes are relatively water tight and stable. The Manning Equation is used for the canal design. Even though this equation was developed for uniform steady state flows, it is widely used for the design of canals as well, as it is very simple and easily optimizes the non-silting and non-scouring hydraulic section.

Traditional canals in spate schemes are usually constructed without drop structures and are far steeper than conventional canals used in perennial irrigation systems (Lawrence P. and Van Steenbergen F., 2005). The canal slopes used for these schemes, which are adopted from the traditional canal routes of the schemes, are 1 : 500 to 1 : 100 (Vertical : Horizontal) depending on the nature of the topography. However, the velocities have been checked using spreadsheet model of the manning's equation and satisfy the non-silting and non-scouring criteria.

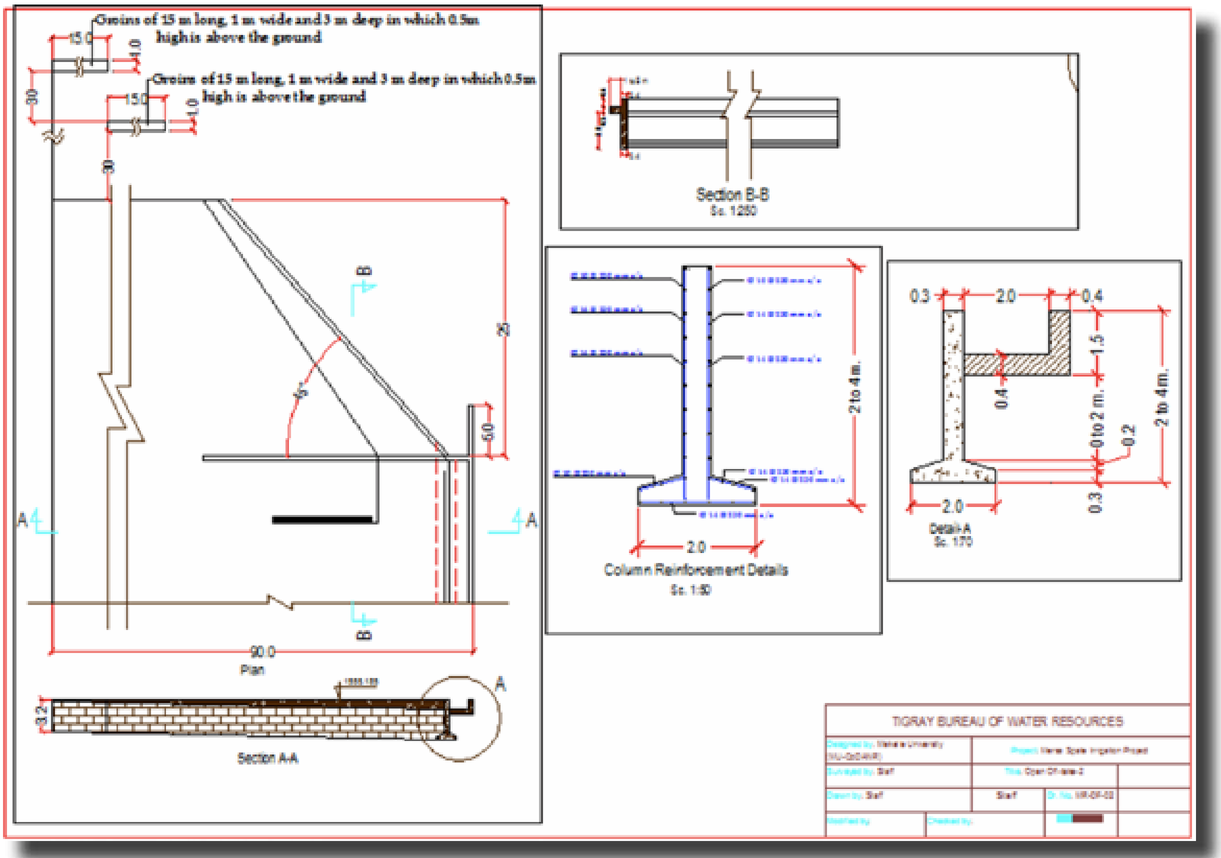


Figure 11: Schematic drawing of open offtake of the hybrid system

3.5 Command area

This study aims to inform the design of sustainable spate systems that optimize the benefits of both traditional and modern systems, without affecting the existing traditional institutional setup of the systems. It is important that this new design diverts enough runoff to irrigate the entire command area. A point that should be noted is that, the irrigation infrastructure may not be used fully in all months as there is a variation in the amount of diverted flood. Therefore, an appropriate estimate of the diverted flood must be done with due consideration to optimizing the cost of the project, meaning the larger the amount of the diverted discharge, the higher the cost of the project (as there will be wider and longer size of idle canals).

The river floods used by spate schemes are unpredictable in timing, frequency and volume (Mehari Haile et al., 2005). Hence, spate systems constitute a risky investment with substantial uncertainty. Attempts have been made to identify relationships between flood peak discharges, flood duration and flood volumes. Studies in Yemen and Eritrea by Arcardis (2004) and Halcrow (1997) however, have shown little or no correlation between peak discharge and flood volumes (Lawrence P. and Van Steenbergen F., 2005). Moreover, floods with a small peak discharge can have a long duration, and a large flood volume, while conversely floods with a large peak discharge can have a very short recession, and a small flood volume. Spate floods are characterized by a very rapid rising limb and they should not be represented using classic triangular hydrograph models such as those of the US Soil Conservation Service (Lawrence P. and Van Steenbergen F., 2005).

The design and operations of the spate irrigation systems requires a good understanding of the hydrology and hydraulics of the flows that are likely to arrive. The following steps are made:

1. The monthly 75 % dependable rainfall has been estimated;
2. The monthly generated flood is estimated using the $Q = CRA$ formula, where Q is the monthly runoff volume (m^3), C is the runoff coefficient, R the monthly 75 % dependable rainfall (m) and A the catchment area (m^2);
3. The monthly diverted runoff volume has been calculated by multiplying the monthly generated flood by the diversion ratio;
4. The monthly demands were calculated using CropWAT software;
5. Using the estimated run off volumes, diversion efficiencies and monthly crop water requirements of the scheme, the irrigation capacity of the runoff has been estimated.

From the analysis in table 2, the Oda spate diversion scheme has an average capacity of irrigating 426 ha with a diversion discharge of 0.5. But, if the diversion ratio is increased to 1, meaning that the river is fully utilized, it will have an average irrigation capacity of 852 ha.

Finally, the design command area is fixed to be 420 ha, as the available command area is only limited to this figure. It should be noted that in

Figure 12: Offtakes in the Oda spate system

Table 2: Summary of the irrigation capacity of the Oda catchment using a diversion ratio of 1

Average Annual Irrigation Capacity				
Month	Monthly demand (m³/ ha)	Monthly Run off volume (m³)	Monthly Diverted Volume (m³)	Irrigable area (ha)
January	0	0	0	
February	0	0	0	
March	374.8	0	0	
April	692.0	0	0	
May	1,537.1	186,312.0	186,312.0	121.2
June	2,038.7	104,800.5	104,800.5	51.4
July	1,854.2	2,726,809.2	2,726,809.2	1,470.6
August	798.4	3,754,852.2	3,754,852.2	4,702.9
September	1,844.3	1,069,657.2	1,069,657.2	580.0
October	668.4	259,200	259,200	387.8
November	0	172,800	172,800	
December	0	86,400	86,400	
Yearly sum	**9,807.8**	**8,360,831.1**	**8,360,831.1**	**852.5**

light of further efforts to improve flood use and increasing demand to utilize the flood particularly in the downstream, there will not be any challenge to use the water up to 852 ha.

3.6 Comparison with previously constructed spate systems

Performance assessment has been undertaken using more than 20 spate schemes that have been constructed by the Tigray water Bureau and REST. Majority of the spates don't function at all and some such as Agbe, Shiwata, Hara and Tirke have lower efficiency. According to M. Kebede et.al, (2016), the overall efficiency including the hybrid systems is around 25 %. Assessments undertaken in the three hybrid schemes (Oda, Mersa and Tsige'a) indicate that, there is an overall irrigation efficiency of 84 % (See table 4 below). But, when previously constructed spate schemes only are considered, the efficiency is reduced to 9 % only.

Table 3: Performance assessment of previously constructed spate systems in Tigray

S.no	Scheme name	Command area		Efficiency (%)
		Designed	Actual	
1	Hara	400	0	0.0
2	Tirke	380	0	0.0
3	Beyru	500	0	0.0
4	Dayu	420	200	47.6
5	Buffie	225	0	0.0
6	Fokisa	500	150	30.0
7	Tengago	500	0	0.0
8	Ula-Ula	210	0	0.0
9	Burka	280	0	0.0
10	Agbe	400	20	5.0
11	Shiwata	250	20	8.0
	Overall	**4,065**	**390**	**9.6**

4. Conclusions

After critically analyzing the design of the two schemes, the following conclusions can be drawn:

- Active participation of farmers have led to the innovation of the hybrid systems design. The hybrid design has contributed towards the sustainability of these spate systems by optimizing the benefits of both traditional and modern systems, without affecting the existing traditional institutional setup of the systems.
- Although irrigation capacity differs from month to month, the average irrigation

Table 4: Performance assessment of hybrid spate systems in Tigray (for the year 2016 only)

S.no	Scheme name	Command area		Efficiency (%)
		Designed	Actual	
1	Oda (Hybrid)	420	416	99
2	Mersa (Hybrid)	430	271	63.0
3	Guguf (Tsige'a)	188	185	98.4
	Overall	**1,043**	**876.5**	**84.0**

capacity of each scheme is designed to be 420 and 430 ha. The overall diversion (irrigation) performance evaluation indicates that, there is 9 % efficiency in the previously constructed spate systems, 84 % flood diversion efficiency (for the year 2016 only) within the hybrid systems and an overall efficiency of 25 %.

- In light of the efforts and political willingness of the Ethiopian government to magnify the coverage of spate systems, design guidelines and manuals of spate irrigation design should be readily available in the coming few years. Hence, these (hybrid) designs can have a place in the development of design guidelines and manuals of spate irrigation design.

5. The way forward

- Flood Based Farming Systems are characterized by their cost effectiveness, huge potential, climate smart and adaptable technologies, as well as being the only viable option in some areas. They are very good alternative water harvesting systems in particularly the lowlands of Ethiopia. The modification, improvement and further refinement of their design should continue to receive attention, for their application in new areas.
- Although there are improvements in the design and construction of spate schemes over time, a number of challenges are still lingering. To fill these gaps, capacity building should be done, focusing on three main aspects. Firstly, in the development, improvement and dissemination of design manuals and guidelines that consider the special properties of the spate flows. Secondly, spate irrigation training should be mainstreamed in the curricula of universities that provide water management courses. Thirdly, short-term training should be provided to engineers and water experts that are currently working on spate irrigation.
- Some of the failures of FBFS are due to a lack of awareness about the differences between conventional irrigation systems and FBFS. Hence, continuous capacity building on the design of FBFS should be key to further harness the potential of FBFS.

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