Support to the Sustainable Management of the Shebelle and Juba Rivers in Southern Somalia Project (GCP/SOM/047/EC)

Hydraulic Behaviour of the Juba and Shabelle Rivers

Basic Analysis for Irrigation and Flood Management Purposes

DRAFT

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Executive Summary

Water resources management of the Juba and Shabelle Rivers involves two major issues, namely flood management and irrigation water supply. The high floods in the Juba and Shabelle Rivers is both a boon and a curse for the people living in the riverine areas. The high floods deposit much needed nutrients in the flood plains as well as provide opportunities for flood recession cultivation. On the other hand, uncontrolled flood water destroys infrastructures and inundates scarce cultivated land and settlements. The continuing deterioration of the flood control and river regulation infrastructure, coupled with unregulated settlement in flood plains and the recent practice of breaching river embankments to access water for wild flood irrigation, have increased the vulnerability of these communities to progressively smaller peak flows.

So far, any meaningful flood protection and preparedness works have been hampered by the unavailability of accurate topographical and geo-morphological data of the two rivers. The available topographical maps with 20m contour intervals were insufficient to undertake any river analysis including flood plain delineation. Thus, the aerial photography data with 25-50 cm vertical accuracy (digital terrain model- DTM) now available at SWALIM have enormous potential to address these issues.

There is also considerable potential for irrigation development from the two rivers. It is estimated that up to 265,000 ha of land could be irrigated in these two basins if the pre-war irrigation infrastructure were brought back into operation.

A study on hydraulic behaviour of the two rivers and their hydrology to support flood forecasting and water resources information management for irrigation purposes was thus needed. Basic analyses dealing with the hydrological and hydraulic behaviour of the Juba and Shabelle Rivers have thus been undertaken. The analysis and information product derived in this study will also be used in the Juba and Shabelle River Atlas SWALIM is preparing[1].

The main outcomes of this study are thus the following:

- Determination of the general hydraulic characteristics of the two rivers
- Estimation of water availability and water balance at key locations

Catchment Characteristics: Upper parts of the catchments of the two rivers lying mostly in Ethiopia contribute most of the flows in the Juba and Shabelle Rivers in Somalia including floods generated by high intensity rainfall in the upper catchments. Hence, drainage basin morphology described by standard indices was derived from the 30m and 90m DEM[2] available for the whole catchment. Sub-basins of major tributaries were delineated and key catchment characteristics such as the areas and perimeters, hypsometric curves, shape factors/elongations, etc were derived.

[1] An outline (table of contents) and major GIS layers of the River Atlas of the Juba and Shabelle River were prepared as part of this study using SWALIM's past work and data from the Digital Aerial Photography carried out in January 2008. The Atlas will cover a general description of the rivers, hydrological and hydraulic regime and the orthophotos with contours, names of major towns, settlements, infrastructure, etc.

[2] Only derived products from 30m DEM are available with SWALIM.

Hydrological and Hydraulic Characteristics : Based on the "Water Resources Assessment of Somalia" prepared under SWALIM Phase-II (GCP/SOM/045/EC), the hydrological features of the Juba and Shabelle River basins were further elaborated including identification of the catchments with special focus on flood hydrology and irrigation water demand. Information and data on river hydraulics and available water for releases for irrigation and flood diversion were assessed.

Aerial Photography Products: The aerial photographs and the relevant DTM were analysed to extract the following geo-morphological, topographical and hydraulic features.

(i) Geo-morphological characteristics of the rivers;

(ii) Cross-sections of the rivers (perpendicular to the flow paths) at relevant intervals including the sections upstream and downstream of the gauging stations, bridges, barrages and, other control structures,

(iii) Mapping of irrigation off-takes along the river course (locations, invert levels); Longitudinal profiles and cross sectional data for primary irrigation canals and barrages that are covered by the aerial survey[3].

River Hydraulics: Theoretical rating curves, bank full conditions and preliminary flood inundation studies in key locations were derived using the HEC-RAS model and HEC Geo-RAS software. The 25cm and 50cm vertical accuracy DTM available from the Aerial Survey was used for this purpose. It should be noted that the bank full conditions should be reliable as the channel hydraulics can be modelled using 1-dimensional river hydraulic models like HEC-RAS. This would however not be accurate for the flood plains as a 2-Dimensional hydraulic model would be required. This was not carried out in this study.

Flood Inundation Mapping: Basic flood inundation mapping at two flood prone locations – Jammame Reach in Juba River and Jowhar Reach in Shabelle was illustrated using the HEC RAS results with further processing using HEC Geo-RAS.

Irrigation Diversions and Water Balance: Irrigation water requirements for general cropping patterns followed in the Juba and Shabelle river areas were derived using FAO CROPWAT software. Mapping of irrigation off-takes along the river course using the aerial photographs and derived DTM were initiated in this study. The off-take levels and the dimensions and profile of the canals can be analysed to derive the capacity of the canals and discharge diverted by these canals in various seasons. This can be used to calculate the water balance of the river at different locations. As the area coverage of the two rivers is quite large, only major diversion canals were mapped.

[3] Mapping of the hydraulic structures and canals will be included in the SWALIM River Atlas

Glossary of Somali Terms

Deshek	Flood-diversion techniques used for delivering flood water for irrigation purposes
Dyer	October to November, minor wet season
Gu	April to June, major wet season
Hagaa	July to September dry and cool season
Jilal	Dry season from December to March
Webi	Perennial Stream

List of Abbreviations

BCM	- Billion Cubic Meters
CP	- Cropping Pattern
CROPWAT	- Crop Water Requirement Software of FAO
EC	- European Commission of the European Union
FAO	- Food and Agriculture Organization of the United Nations
DEM	- Digital Elevation Model
DTM	- Digital Terrain Model
Geo-RAS	- GIS Processor for HEC-RAS
HEC-RAS	- Hydrological Engineering Centre River Analysis System Model of USACE
SRTM	- Shuttle Radar Topography Mission
SWALIM	- Somalia Water and Land Information Management Project of FAO
USACE	- United States Army Corps of Engineers

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1. Introduction

The alluvial plains of the two Somali perennial rivers, the Shebelle and Juba Rivers, have been and could be the breadbasket of Somalia. They have considerable potential for irrigation development. The civil war in the last two decades has however taken a severe toll on the institutions and infrastructure necessary to manage the water resources of the two rivers that is the lifeline of Southern Somalia. Flooding is now a frequent problem in the riverine areas and sometimes it takes the proportion of a catastrophic natural disaster, like in the 2006 Deyr rainy season. Natural flood plains have been encroached and the embankments have been cut to divert water during the dry season for irrigation purposes. The barrages and canals that were used to irrigate vast areas are now dysfunctional. Efforts are underway to prepare an integrated flood management plan and also to rehabilitate the irrigation facilities and revive the agricultural sector. These efforts are hampered by lack of knowledge of river basin behaviour in terms of hydrology, hydraulics, sedimentation, etc. and, lack of public institutions responsible for implementing sound river basin management measures.

FAO-SWALIM has recovered available historical data and collected valuable data on water and land resources over the past few years to support sustainable management of the Juba and Shabelle river basins. A Digital Aerial Photography Survey of the Juba and Shabelle Rivers has been carried out in January 2008 and a topographical dataset with 25 to 50 cm vertical accuracy is now available. These data will assist in flood control and irrigation management among other important applications. This will enable improved humanitarian response and action and also to develop long term solutions in the riverine areas of Southern Somalia.

1.1 Problem Analysis

Water resources management of the two rivers involves two major issues, namely flood management and irrigation water supply. The high floods in the Juba and Shabelle Rivers inundate scarce cultivated land along the river course regularly. The continuing deterioration of the flood control and river regulation infrastructure, coupled with unregulated settlement in flood plains and the recent practice of breaching river embankments to access water for wild flood irrigation, have increased the vulnerability of the riverine communities to progressively smaller peak flows. The deposition of high sediment yield of the river course confined within embankments has raised the bed level over the years. Hence, the river banks are regularly breached and the areas surrounding the river courses both in the Juba and Shabelle Rivers are flooded every other year.

Various natural and human actions summarized below have aggravated the flood problems even during normal flows:

- River bed levels rising higher than adjacent land due to sediment deposition,
- Breaching levees for irrigating land in dry seasons,
- Natural flood plains being encroached,
- Unplanned closure/opening of natural flood relief channels,
- Total break down of the existing irrigation infrastructure and,
- Absence of central or local governance managing the river basin.

There is considerable potential for irrigation development from the two rivers. It is estimated that up to 265,000 ha (source: “Banana Sector Study”) of land could be irrigated in these two basins if the pre-war irrigation infrastructure were brought back in operation. Based on the conclusions and recommendations of the "Banana Sector Study", efforts are on by various donor agencies including the European Community (EC) to restore the irrigation facilities and revive the agricultural sector for about 19,000 - 31,500 hectares, most of them on the Middle and Lower Shabelle. Private entrepreneurs are also investing to rehabilitate and maintain formerly irrigated plantations.

The pre-war irrigation schemes have now been in a state of disrepair with most of the barrages and canals silted up and the gates and intakes inoperable due to lack of maintenance as well as due to intentional destruction of the structures during the conflict. In the 1920s, the Italian colonizers introduced controlled irrigation to grow a wide range of commercial crops such as cotton and bananas. Since then a number of irrigation schemes were developed in the Juba and Shabelle Rivers. There were altogether ten barrages (one in Juba and nine in Shabelle) that were constructed to regulate flows to the canals supplying irrigation water to these irrigation schemes

1.2 Constraints and Limitations

The topographical features of the Juba and Shabelle rivers could be accurately derived from the aerial photographs and DTMs but the availability of field data such as the discharge measurements and gauging data for key locations is important for determining the hydraulic and hydrological characteristics of the rivers. While the staff gauge data are available in three stations each in the Juba and Shabelle Rivers after 2001, rating curves have not been updated due to difficulty in discharge measurements to date. The aerial photography was carried out during the month of January when the river flows were the lowest and the unavailability of under-water profile could be a constraint for defining the full cross-sections of the rivers for hydraulic calculations.

On the other hand, more than 90% of the flows in the two rivers are contributed by catchments outside the Somali territory and the required rainfall, river flows and catchment characteristics data from these catchments are not available to undertake any basin wide hydrological study of the two rivers.

Detailed hydrological analysis of the two rivers has been covered in the Water Resources of Somalia Report that was produced in SWALIM phase-two. This report focuses and summarizes the basic hydrological analysis related to flood hydrology and irrigation water availability.

1.3 Objectives

The overall objective of this study is to prepare the basic analyses needed to determine the hydraulics of the two rivers and their hydrology to support flood forecasting and flood management and water resources management for irrigation purposes. Some of the analyses and information product derived in this study will be used in the Juba and Shabelle River Atlas SWALIM is preparing.

The main outcomes of the study are thus the following:

1. Determination of the general hydraulic characteristics of the two rivers
2. Estimation of water availability and water balance at key locations

The first outcome is based on the hydraulic and hydrological data available and the derivation of the geo-morphological and topographical characteristics of the two rivers from the aerial photographs digital terrain model (DTM) and other available DEMs.

Water balance in the two rivers is estimated using historical hydrological flow data and estimates of irrigation diversions.

The outcomes will contribute to meeting the following expected result of the “Sustainable Management of the Shabelle and Juba Rivers in Southern Somalia” Project of SWALIM “Result 2: Essential baseline data for river management are collected, analysed and available to planners, decision-makers and local institutions;”

The study concentrates on the portion of Juba and Shabelle basins within Somalia as shown in Figure-1.

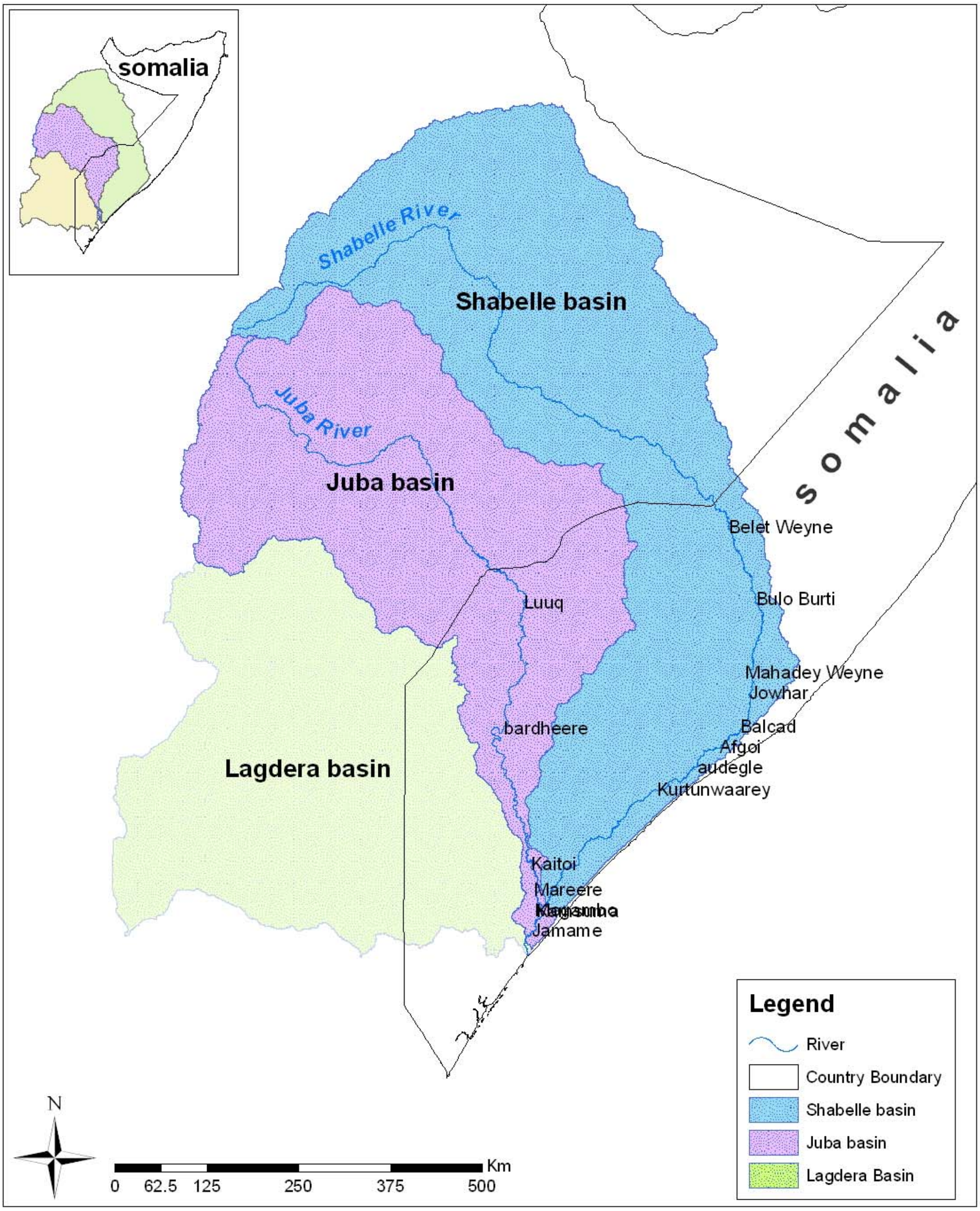


Figure 1 : Map showing coverage of Juba and Shabelle and Lag Dera Basins

1.4 Approach and Methodology

The general approach and methodology adopted in this study is as follows:

1.4.1 Catchment Characteristics

The upper parts of the catchments of the two rivers; lying mostly in Ethiopia, contribute most of the flows in the Juba and Shabelle Rivers in Somalia including floods generated by high intensity rainfall. Hence, drainage basin morphology described by standard indices is important for hydrological purposes including flood forecasting and rainfall runoff relationships. These were derived from the 30 m[4] and 90 m spatial resolution DEM available for the whole catchment. Sub-basins of major tributaries were delineated and key catchment characteristics such as the area and perimeter, hypsometric curves, shape factors/elongations, etc., were derived.

Based on the physical and hydro-meteorological data of the catchment areas contributing to flows in the two rivers, general hydrologic features of the two river basins will be prepared. Development of relationships between the derived drainage indices and hydrological parameters at this stage would however be pre-mature as rainfall and discharge data time series (daily) are not available for the catchments within Ethiopia.

1.4.2 Hydrological and Hydraulic Characteristics of the two Rivers

Based on the "Water Resources Assessment of Somalia" prepared under SWALIM phase-two (GCP/SOM/045/EC), the hydrological features of the Juba and Shabelle River basins were elaborated in details including identification of the catchments with special focus on flood hydrology and irrigation water demand. Information and data on river hydraulics and available water for irrigation and flood diversion were assessed.

The aerial photographs and the relevant DTMs were analysed to extract the following geo-morphological, topographical and hydraulic features.

- (i) Geo-morphological characteristics of the rivers,
- (ii) Cross-sections of the rivers (perpendicular to the flow paths) at relevant intervals including the sections upstream and downstream of bridges, barrages and other control hydraulic structures,
- (iii) Mapping of irrigation off-takes along the river course (locations, invert levels); longitudinal profiles and cross sectional data for primary irrigation canals and barrages that are covered by the aerial survey[5].

1.4.3 Irrigation Requirements and Water Balance

Irrigation water requirements for general cropping patterns followed in the Juba and Shabelle rivers area were derived using FAO Crop Water Requirement Model (CROPWAT) software.

[4] Only derived products from the 30m DEM are available at SWALIM
[5] The hydraulic structures and canals will be included in the River Atlas

The climatic data for Jilib and Afgoi climatic stations were used for crop water requirement calculations[6].

Mapping of the off-takes of primary irrigation canals along the rivers course using the aerial photographs and derived DTMs were carried out during this study (See **Annex C**). The off-takes level and the existing dimensions and profile of the canals can be analysed to derive the capacity of the canals and discharge diverted by these canals in various seasons. This can be used to calculate the water balance of the river at different locations. Mapping of the other canals is planned under an activity specifically designed for processing of the aerial photography data and will be presented in the Juba and Shabelle River Atlas currently being prepared.

[6] The cropping pattern considered here is with irrigation in the dry season also. At present, there is little irrigation currently practiced in the dry season due to no water available.

2. Catchment Characteristics

2.1 Juba River Basin

The Juba River is known as the Genale Dawa River within Ethiopia. There are three main tributaries, Webi Dawa, Genale and Webi Gestro in its upper catchment which all flow south-eastwards. The three main tributaries have catchments of approximately 24,860 km^2, 57,044 km^2 and 59,020 km^2, respectively. Gestro and the Genale unite to form the Juba River just north of Dolo in Ethiopia, and the Dawa joins the Juba River at Dolo having formed the Kenya-Ethiopia border and the Somalia-Ethiopia border in the area west of Dolo.

Shabelle and Lag Dera Rivers join the Juba River before it reaches the sea although most of the little water left in the two rivers is lost in the swamps before reaching the Juba with the exception during high rainfall. Technically, both Shabelle and Lag Dera are part of the Juba Basin. The total catchment area of the Juba Basin excluding Shabelle and Lag Dera catchment at the mouth of the river near Kismayo is about 221,000 Km^2 based on catchment delineation in SRTM 30m from USGS, 65% of which is in Ethiopia, 30% in Somalia and 5% in Kenya. The catchment areas of Shabelle and Lag Dera are not included although both of them are technically tributaries of Juba as explained earlier.

The basin is spread from sea level at its mouth where it flows into the Indian Ocean in Somalia to well above 3000m above mean sea level in the northwest in Ethiopia (
Figure 3). About 42% of the catchment area is below 500m, 43% between 500-1500m, 14% between 1,500-3,000m and 1% above 3,000 m. The catchment area within Somalia is below 700m (
Figure 4). Slopes in the upper part of the catchment in Ethiopia and Kenya are generally steep with well developed drainage networks. In the middle and lower part of the basin below 500m, the slopes are gentle and the drainage network is less dense. There is little flow contributed in the basin area within Somalia as the network is not well developed and there is no major tributary.

The total length of the Juba River is about 1,808 Km as measured on the longest tributary, of which 804 Km lies in Ethiopia and 1,004 km lies in Somalia based on SRTM 30m derived streams from USGS. The total length of the longest tributary (the Genale) from its source to the confluence with the Gestro and Dawa is about 714 km. After entering Somalia, the river continues to flow south-easterly until it reaches the town of Luuq (also called Lugh Genanah), from which point it flows towards South and reaches the Indian Ocean. The gradient of the river is steep in the upper reaches but is very mild in the lower reaches especially within Somalia. The basin morphology data derived from 90m SRTM DEM is presented in Table-1.

2.2 Shabelle River Basin

The Shabelle River rises on the eastern flanks of the eastern Ethiopian highlands, the highest point being 4,230m. The total catchment area of the Shabelle River at its confluence with the Juba River is about 297,000 km2 (based on catchment delineation using SRTM 30m from USGS), two-thirds (188,700 km2) of which lies in Ethiopia and the rest (108,300 km2) is in Somalia. The elevation of the basin varies from about 20m above sea level in the south to

more than 3000 m on the Eastern Ethiopian Plateau (Figure-3). About 47% of the basin is below 500m, about 41% is between 500 to 1,500m, 12% is between 1,500 to 3,000m and less than 1% is above 3,000m (
Figure 4). Within Somalia, the catchment area is below 700m (Table-1).

The river and its tributaries in the eastern Ethiopian highlands are deeply incised and the slopes are steep. The total length of the main course of the river from the source to the Somalia border is about 1,290 Km and it traverses to additional distance of 1,236 Km within Somalia before it meets the Juba River. Its main tributaries in Ethiopia are the Fanfan (northern part of the basin) and the Webi Shabelle (Figure 2). The catchment areas of Webi Shabelle and Fanfan are 143,278 Km^2 and 44, 867 Km^2, respectively. The flows in the Fanfan tributary are intermittent and flows from it reach the Shabelle River only during high rainfall periods. The drainage network in the Ethiopian part of the catchment (especially in the western part) is dense to very dense except in the bordering region with Somalia and east of longitude 44^0 E.

The Shabelle River flows south-eastwards to the Somali border at the border town of Ferfer. There, it turns south to Balcad near Mogadishu, where it turns southwest and continues roughly parallel to the coast from which it is separated by a range of sand dunes. Half way along the coastal stretch, it runs into a series of swamps. Downstream of the swamps the river resumes a defined channel, but flows are very much reduced and the river discharges into the Juba only in times of exceptional floods. The swamp areas (wetlands) which are fed by Shabelle would have high ecological value in terms of habitat for flora and fauna as well as recharge areas of the groundwater aquifers lying in the area. Unfortunately, no data is available on these swamps. It could however be safely said that the swamps sustain the freshwater available in the aquifers which meets the water needs of the coastal towns and settlements in the south. Further study would however be required to assess the hydro-geological conditions of the area.

The drainage network in the Somalia part of the basin is thin and non-existent. The small streams with small catchment are of ephemeral type, where there is flow only during heavy rainfall. A number of streams are found in Buur escarpment which is fed by springs.

The basin morphology data for sub-basins based on the gauging station locations derived from 90m SRTM DEM is presented in Table-1.

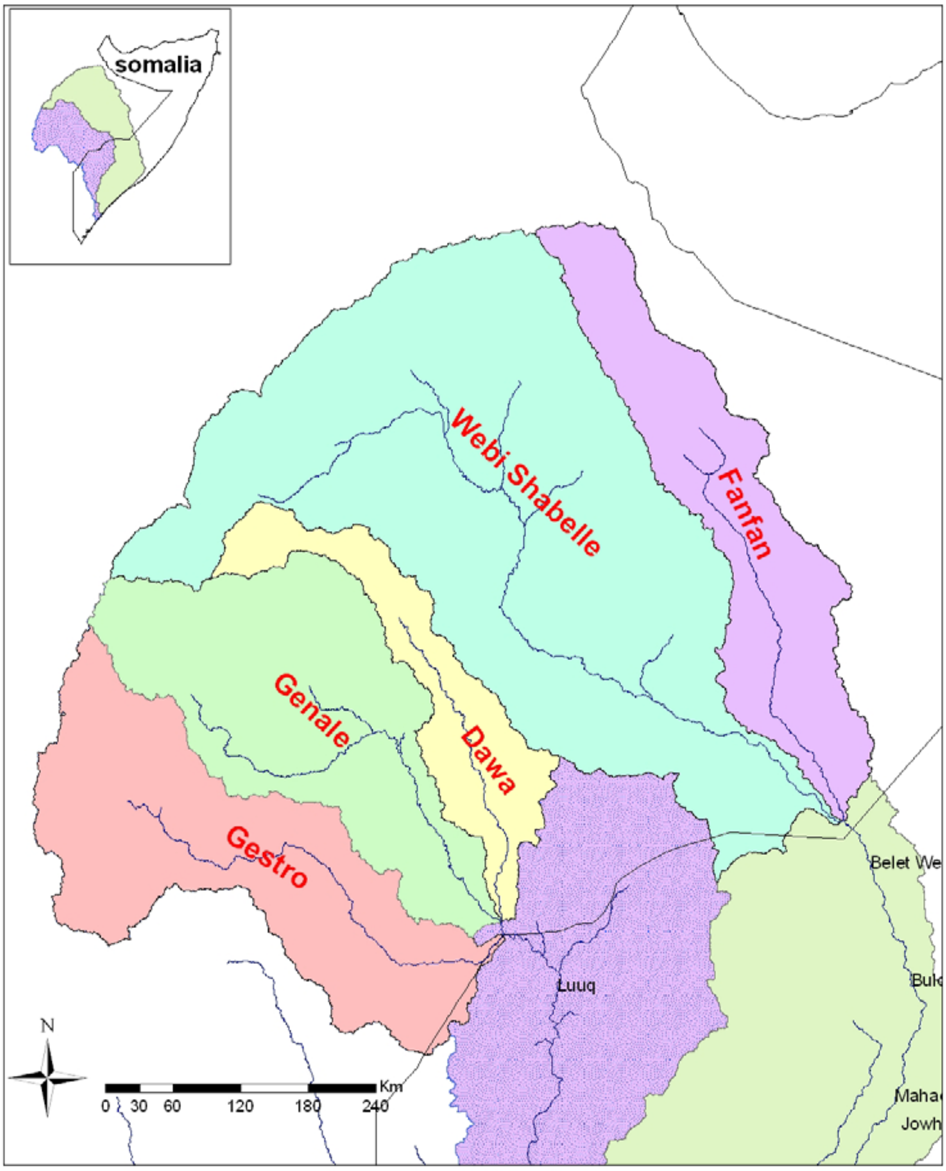


Figure 2 : Sub-basins of the Juba and Shabelle Rivers within Ethiopia

Table-1: Juba and Shabelle River Basin Morphology based on SRTM 90m DEM

Baisn	Catchment Area (Km^2)	Perimeter (Km)	Max Elev. (m)	Min Elev. (m)	Mean Elev. (m)	L_Max (Km)	L_Eqv (km)	L_Relat
Juba								
Gestro Sub-basin	59,020	1,840	3078	176	1,130	772	851	3.18
Genale Sub-basin	57,044	1,539	4373	181	1,254	714	700	4.53
Dawa Sub-basin	24,862	1,472	4337	181	982	755	687	3.16
at Luuq	168,738	2,510	4373	146	1,026	874	1102	2.13
at bardheere	200,349	2,778	4373	91	921	1,107	1226	2.47
at Kaitoi	214,729	3,191	4373	31	873	1,404	1447	3.03
at Mareere	215,604	3,330	4373	20	870	1,456	1523	3.14
at Kamsuma	216,710	3,396	4373	12	866	1,487	1559	3.19
at Jamaame including Shabelle catchment	514,366	4,186	4373	7	792	2,078	1808	2.90
Shabelle								
Wabi Shabelle	143,278	2,645	4158	199	1,100	1,183	1203	3.13
Fanfan	44,867	1,717	2993	199	874	751	803	3.55
at Belet Weyne	193,224	2,873	4158	182	1,026	1,238	1286	2.82
at Bulo Burti	207,488	3,052	4158	145	979	1,373	1375	3.02
at MahadeyWeyne	209,865	3,372	4158	109	970	1,507	1551	3.29
at Jowar	210,040	3,429	4158	102	969	1,534	1582	3.35
at Balcad	214,516	3,497	4158	85	953	1,603	1616	3.46
at Afgoi	244,672	3,582	4158	75	873	1,660	1642	3.36
at Audegle	245,069	3,635	4158	72	872	1,689	1671	3.41
at Kurtunwaaray	256,028	3,772	4158	59	842	1,771	1739	3.50
at Juba Confluence	296,252	4,290	4158	13	741	2,041	1997	3.75

Note:

L_max_Km – is the length of the longest flow path of the watercourse in kilometres. The distance from the pour point along the longest watercourse to the catchment boundary

L_eqv_Km – is the equivalent length of catchment (Le) in kilometres. It is the longer side of the rectangle which has the same area and perimeter as the catchment. $L_e = \frac{\sqrt{(P + P^2 - 16 * A)}}{4}$ (Traditional operator precedence rule is used to show the formula). If P^2-16*A < 0 then the script P^2-16*A = 0 applies to a square and P^2-16*A < 0 to a circle.

L_relat – is the relative longest watercourse length (L_r), dimensionless. Large values indicate an elongated catchment or meandering river. $L_r = \frac{L}{\sqrt{A}}$ is used by the Department of Water Affairs and Forestry, South Africa.

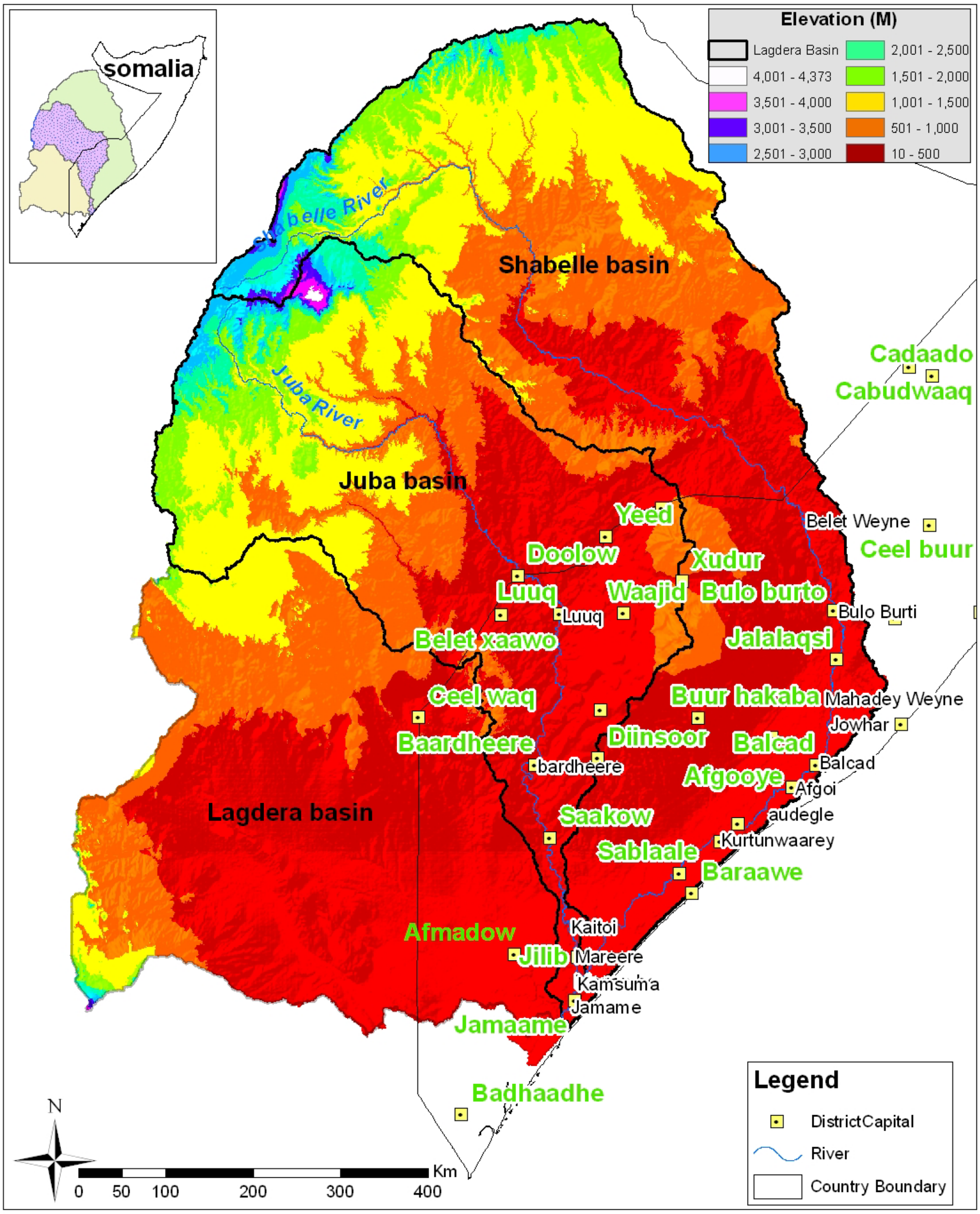
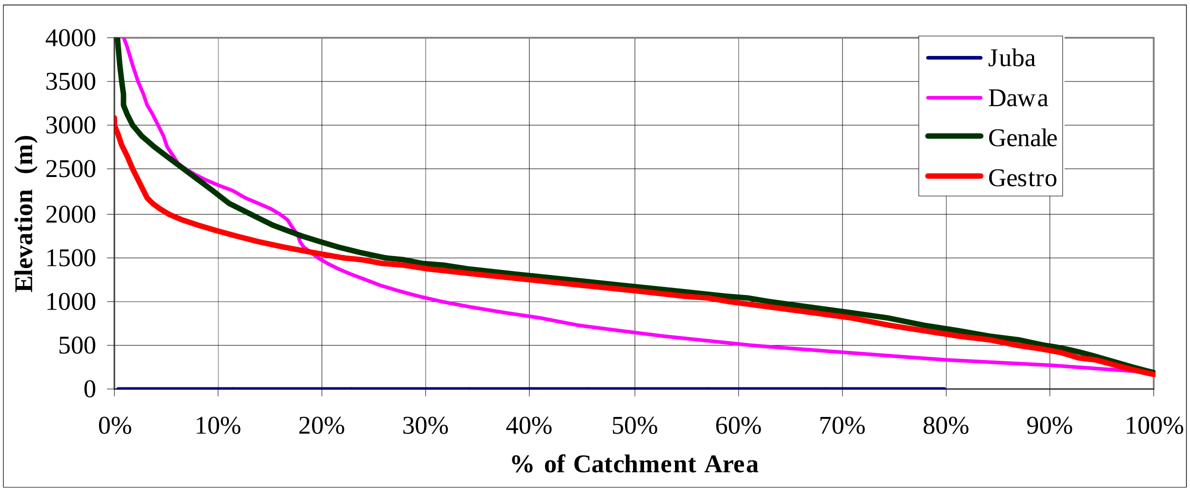
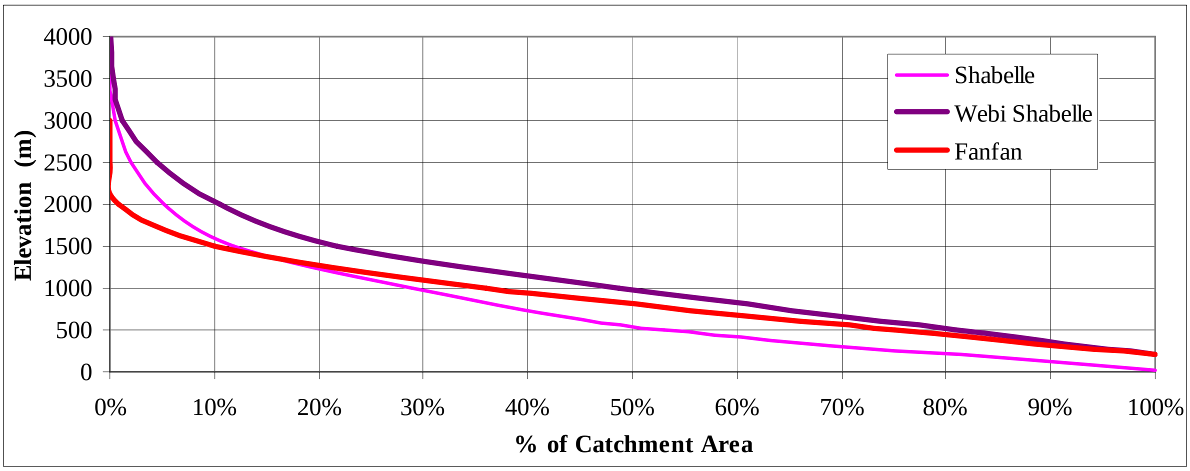


Figure 3 : Elevation Variation of the Juba and Shabelle River Basins





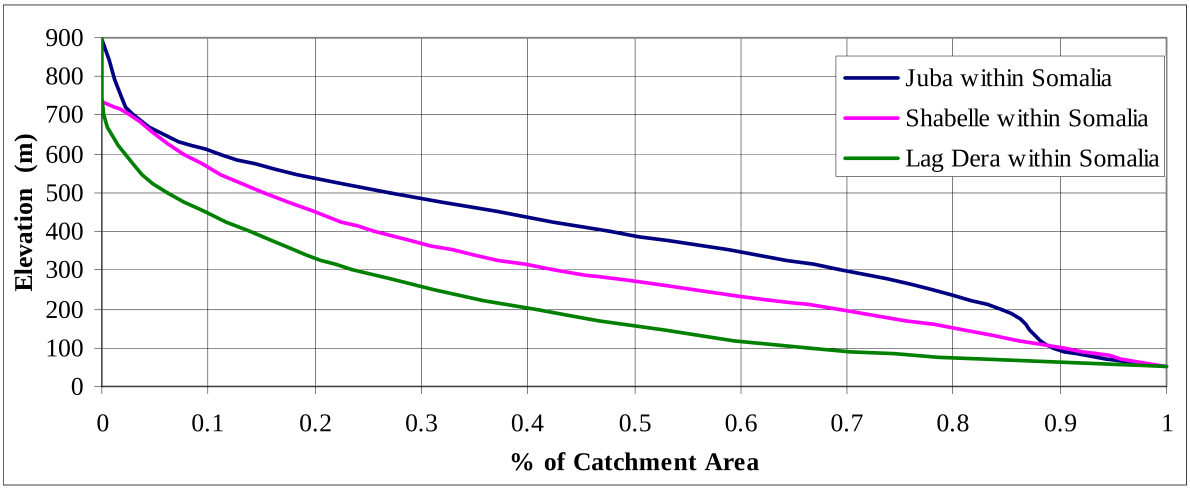


Figure 4 : Hypsometric Curves for Juba, Shabelle and Lag Dera Basins

Table 2 ; Topographic (Hypsometric) Data for the Juba and Shabelle Basins

Basin	Area (km^2)	Max. Elev. (m)	Min. Elev. (m)	% of Catchment Area in different elevations (m)							
				<500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000-3500	>3500
Juba	210,010	4,139		42%	22%	21%	8%	4%	2.1%	0.5%	0.1%
Dawa	296,232	4,337	181	39%	30%	12%	4%	9%	2.6%	1.9%	2.3%
Genale	296,232	4,373	181	10%	26%	37%	13%	6%	5.0%	1.0%	0.8%
Gestro	296,232	3,078	176	13%	28%	37%	17%	4%	1.7%	0.0%	0.0%
Shabelle	296,232	4,158	13	47%	24%	17%	7%	3%	1.6%	0.4%	0.0%
Webi Shabelle	143,277	4,155	199	19%	32%	27%	11%	6%	3.3%	0.9%	0.3%
Fanfan	296,232	2,993	199	25%	39%	26%	9%	1%	0.0%	0.0%	0.0%

Basins within Somalia	Area (km^2)	Max. Elev. (m)	Min. Elev. (m)	% of Catchment Area in different elevations (m)								
				<50	50-100	100-200	200-300	300-400	400-500	500-600	600-700	>700
Juba	61,395	894	-	10%	5%	15%	22%	20%	16%	8%	2.8%	0.3%
Shabelle	102,806	735	4	9%	21%	27%	17%	10%	8%	5%	2.5%	0.1%
Lag Dera	43,789	903	-	34%	26%	18%	9%	8%	4%	2%	0.1%	0.01%

3. Hydrological and Hydraulic Regime

3.1 Long Term Annual Flows

Ninety percent of the flows in Juba and Shabelle Rivers within Somalia are contributed by the catchment outside Somalia (75% of the total catchment). Based on stream flow data from 1963 to 1990, the long-term mean annual flow volumes in the Juba River at Luuq (catchment area of 168,738 Km^2) and at Jammame (catchment area of 218,114 Km^2) are 5.9 billion cubic meters (BCM) and 5.4 BCM, respectively. The annual flows in the Shabelle River at Belet Weyne (catchment area of 207,488 Km^2) and at Awdgegle (catchment area of 245,069 Km^2) are 2.4 and 1.4 BCM, respectively[7]. The annual runoff to rainfall ratios or, the runoff-coefficients is about 6.5% and 2.1% in Juba at Luuq and Shabelle at Belet Weyne, respectively. Annual flows decrease as the river flows downstream. This is mainly due to various factors such as: not much contribution to flows from the Somali catchment areas, frequent occurrence of bank full condition and spilling of flood water into the flood plains and natural flood relief channels, river diversions for irrigation both during low and high flow periods, and losses due to evaporation and infiltration/recharge of the groundwater along the river. It is also seen that the flow in the Juba River is more than the flow in Shabelle River although the catchment area of the latter is larger than the former. This is due to the different geological formations and higher rainfall in the upper catchments of the Juba River.

Table 3: Annual Runoff Volume along the Juba and Shabelle Rivers in Somalia

Basin Location	Area (Km^2)[8]	Mean (MCM)	Standard deviation (MCM)	Coefficient of Variation (CV)
Juba River				
Luuq	168,738	5,878	1,823	31%
Bardheere	200,349	6,156	1,873	30%
Marere	215,604	5,866	2,018	34%
Kaitoi	214,729	5,617	1,687	30%
Jammame	218,114	5,345	1,514	29%
Shabelle River				
Belet Weyne	193,224	2,365	713	30%
Bulu Burti	207,488	1,410	337	24%
Mahadaye Weyne	209,865	2,053	483	23%
Balcad	214,516	1,596	315	20%
Afgoi	244,672	1,501	382	26%
Awdhegle	245,069	1,410	337	24%

[7] Source: Basnyat, Divas B., 2007**:** Water Resources of Somalia. FAO-SWALIM (GCP/SOM/EC045) Project Technical Report N^o W-11, Nairobi, Kenya.

[8] Note: Catchment areas are based on delineation using the 90m SRTM DEM.

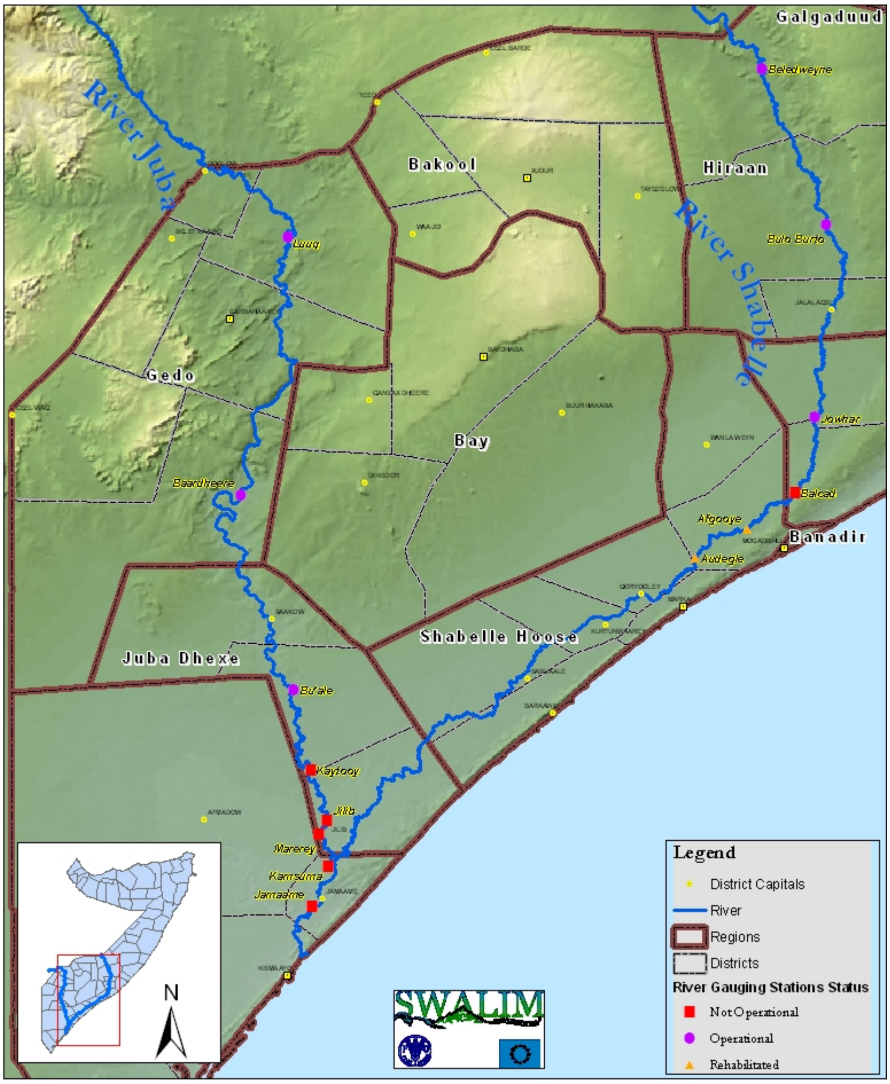


Figure 5: Location and Status of the Hydrometric Gauging Stations

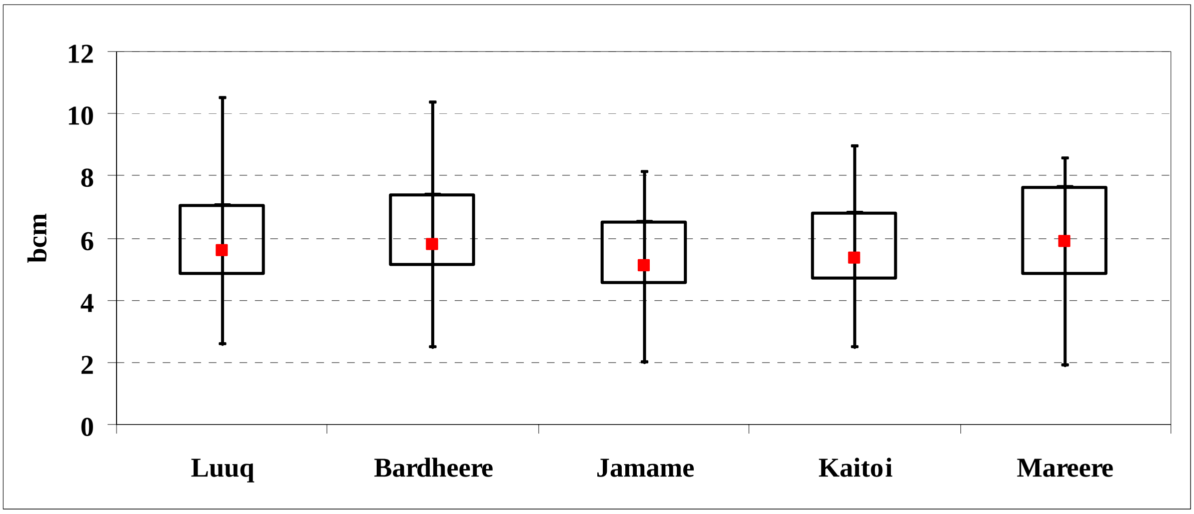


Figure 6: Annual Runoff along the Juba River

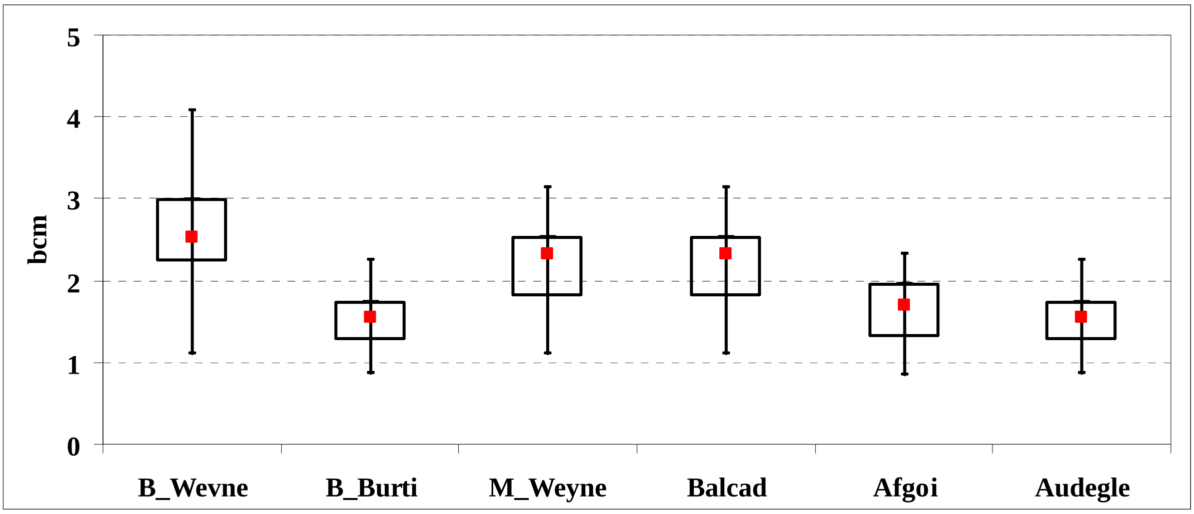


Figure 7 : Annual Runoff along the Shabelle River

3.2 Long Term Monthly Flows

The monthly flows decrease along the river with water being lost through extraction, evaporation and over-bank spillage. Figure 8 presents the flow variations along the Juba River for each month and Figure 9 presents the annual hydrograph for the most upstream and downstream gauging stations in the Juba River. Figure 10 and Figure 11 are the corresponding figures for the Shabelle River. The monthly flows are generally decreasing from upstream locations to downstream locations with some marginal increase during the rainy seasons in some downstream locations due to contribution from the Somali catchments. There is also more reduction in flows in the Shabelle than in the Juba signifying more consumptive water use and also more over bank spillage in the Shabelle than in the Juba River.

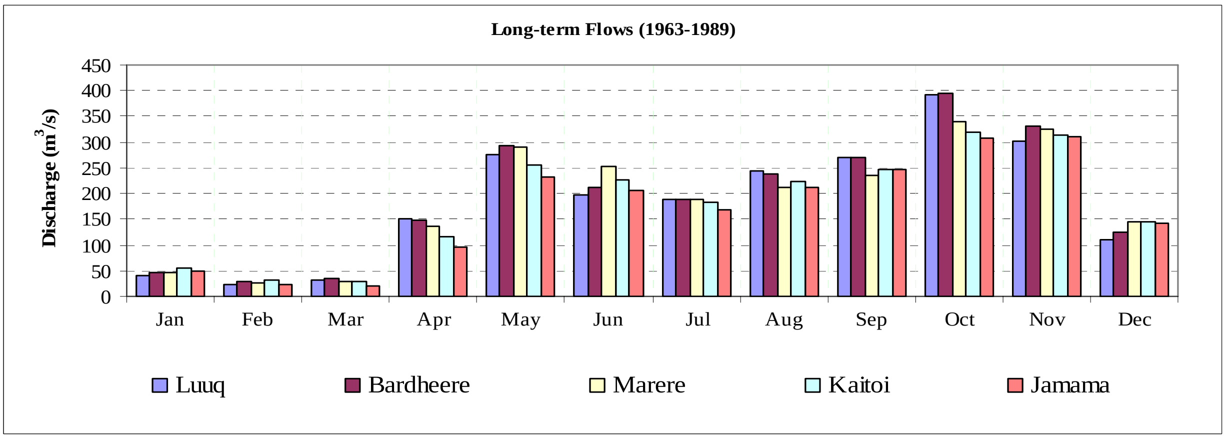


Figure 8 : Flow Variation along the Juba River

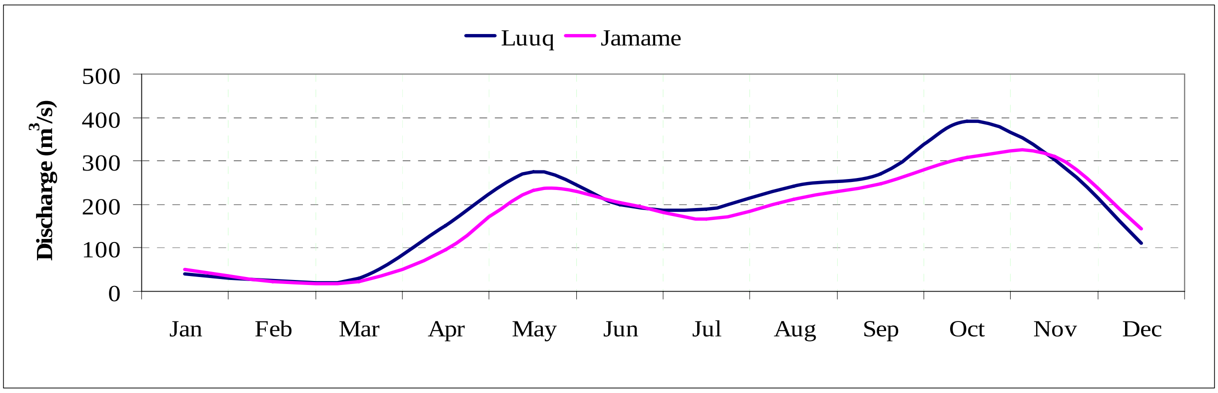


Figure 9 : Flow Variation in Most Upstream (Luuq) and Most Downstream (Jamaame) Stations in the Juba River

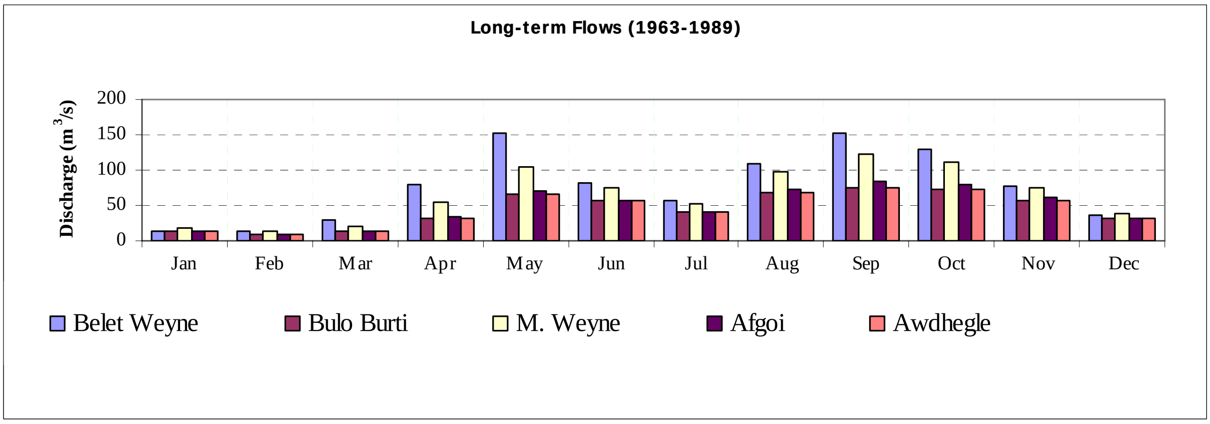


Figure 10 : Flow Variation along the Shabelle River

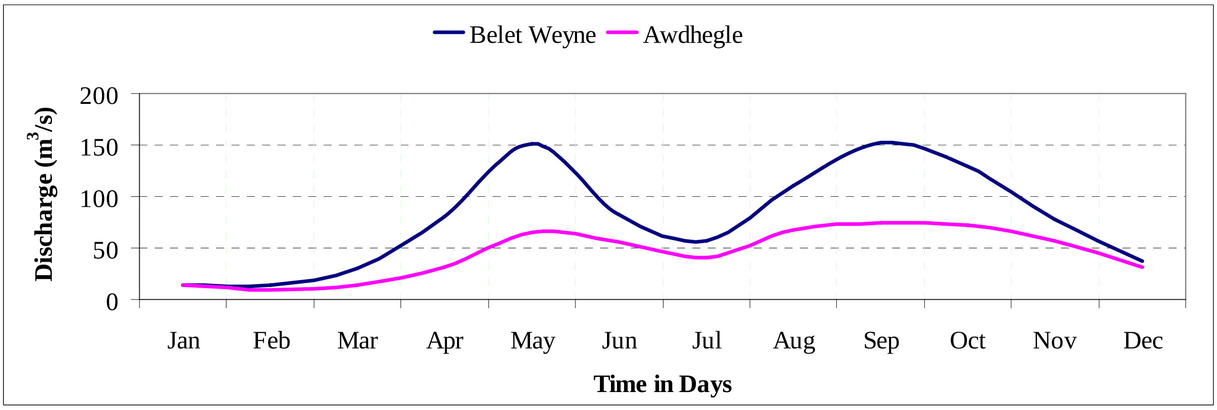


Figure 11 : Flow Variation at Most Upstream (Belet Weyne) and Most Downstream (Awdhegle) Stations in the Shabelle River

Table 4, Table 5, Figure 12 and, Figure 13 present the flow duration curves for Juba River at Luuq and Shabelle River at Belet Weyne, respectively. Annex-A presents the summary of flow statistics at different locations in the two rivers including flow duration and 10-day flow statistics.

Table 4 : Flow Duration Curve for Juba River at Luuq (m^3/s)

%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
5	102.2	76.2	170.2	494.8	651.8	472.8	355.2	418.9	448.6	847.8	674.6	288.6	508.4
10	79.8	58.3	67.0	390.5	550.4	357.3	282.6	379.6	409.1	734.7	506.9	239.8	404.0
20	60.6	36.2	36.4	216.7	418.7	271.7	248.9	326.6	368.7	560.0	412.6	174.0	297.5
30	49.5	27.5	19.2	166.6	335.0	223.9	222.7	282.1	330.4	483.7	339.1	120.8	237.4
40	35.3	20.4	13.8	126.8	265.9	197.9	197.3	249.7	291.5	397.3	287.3	98.3	192.9
50	30.0	16.0	10.3	91.1	222.3	169.9	182.8	227.9	263.7	327.9	244.2	81.6	151.8
60	25.5	12.3	8.4	52.6	182.2	142.7	166.8	205.8	239.2	287.9	208.3	66.7	106.2
70	21.6	9.9	7.1	34.4	146.4	119.0	151.3	186.9	213.3	253.4	164.4	54.8	62.1
80	17.3	6.4	5.5	15.3	102.1	96.0	122.0	161.1	170.8	217.4	135.1	46.0	30.9
90	12.0	5.3	3.2	6.0	61.5	78.3	91.9	128.9	127.1	167.2	102.8	36.7	12.1
95	9.0	2.2	1.3	4.6	34.5	58.5	69.4	107.9	112.0	147.0	85.0	30.0	6.4

Note: the % in the first column is the probability of flow exceedance

Table 5 : Flow Duration Curve for Shabelle River at Belet Weyne (m^3/s)

%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
5	34.4	43.2	130.9	209.6	341.7	295.5	109.2	175.8	243.4	261.1	235.3	118.9	228.3
10	27.6	25.4	97.0	169.2	324.5	192.7	100.3	159.9	219.6	217.3	203.7	84.3	187.7
20	21.3	17.9	56.8	129.6	242.4	124.7	82.5	138.3	198.1	184.9	121.9	57.3	137.0
30	18.0	15.2	21.6	102.6	197.3	85.4	70.2	132.2	177.3	156.9	86.7	35.8	109.5
40	12.5	12.9	13.9	81.6	146.3	66.3	61.9	125.4	164.2	136.0	64.4	23.8	81.7
50	10.5	8.6	11.3	64.2	130.4	52.6	54.6	116.4	153.2	118.7	46.7	17.9	60.7
60	8.6	6.5	7.3	44.3	109.8	42.4	48.0	105.6	141.7	101.3	39.0	14.0	41.6
70	7.1	5.4	5.0	28.3	84.3	33.9	39.4	92.7	122.7	85.2	30.7	12.2	24.3
80	5.8	4.7	3.8	14.6	63.8	28.0	30.9	77.7	99.1	69.1	22.6	10.0	14.3
90	3.3	3.3	2.6	8.3	40.4	18.1	17.3	52.1	69.4	51.9	17.8	7.0	7.4
95	2.4	2.7	2.0	3.0	26.0	14.0	13.8	37.2	60.2	44.3	14.2	5.7	4.6

Note: the % in the first column is the probability of flow exceedance

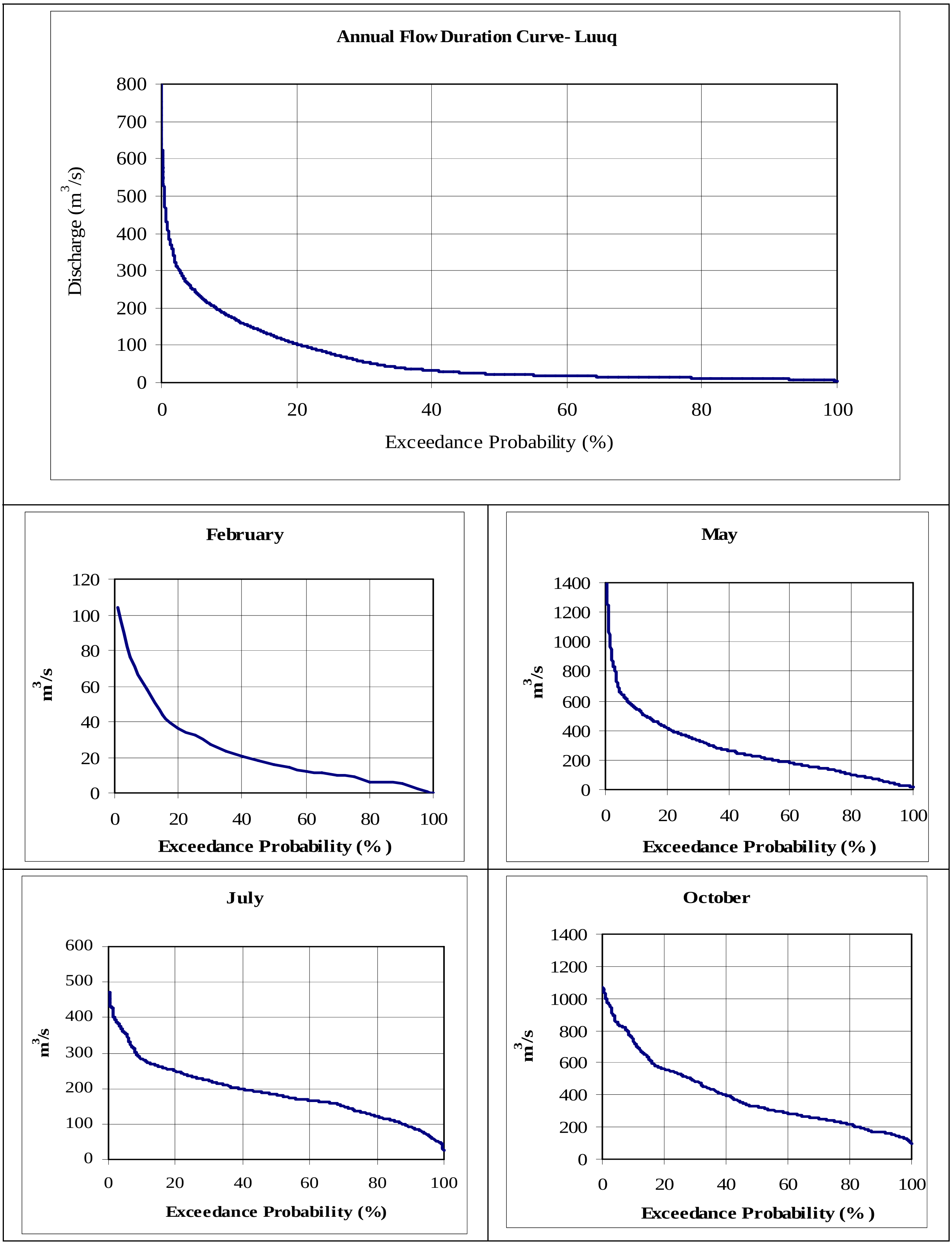


Figure 12 : Flow Duration Curves of Juba at Luuq

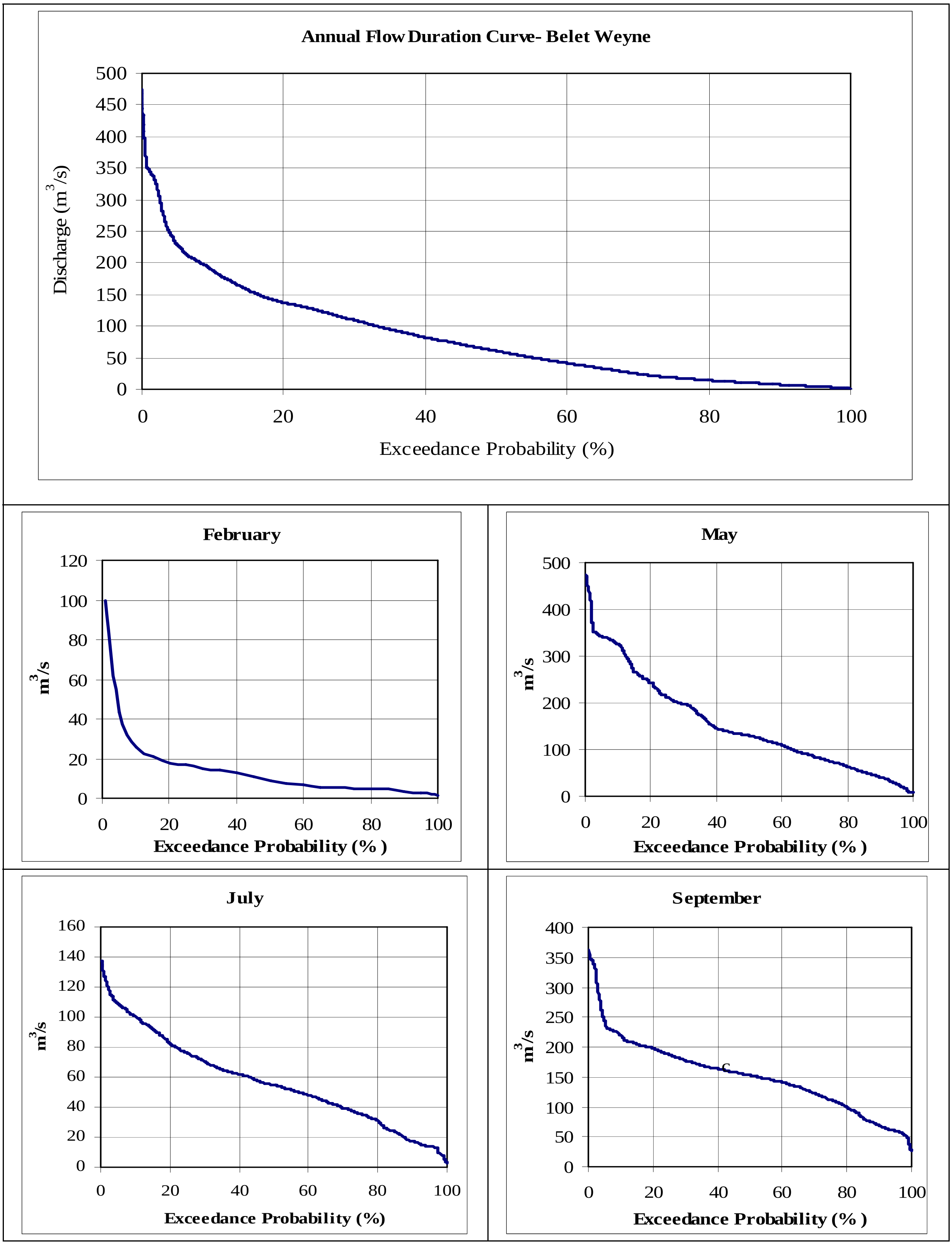


Figure 13 : Flow Duration Curves of Shabelle at Belet Weyne

3.3 High Flows

The maximum annual flows at the different locations of the two rivers are presented in **Table 6** and **Table 7**. **Table 8** presents summary of the annual maximum flows. It can be seen that there is considerable peak attenuation as the river flows downstream. This is both due to channel storage as well as over-bank spillage. Note the high flows in 1977 and 1981.

Table 6 : Annual Maximum Discharge (m^3/s)

Year	Belet Weyne	B Burti	M Weyne	Afgoi	Awdegle	Luuq	Bardheera	Jamame	Mareera
1951	343.2					1080.5			
1952	NA					857.0			
1953	NA					770.3			
1954	258.5					916.3			
1955	174.5					619.3			
1956	377.8					NA			
1957	303.9					650.0			
1958	NA					NA			
1959	208.4					1113.5			
1960	138.5					NA			
1961	395.9					1181.0			
1962	NA					NA			
1963	351.4	306.2	135.4	96.8	74.7	689.0	642.4	459.2	
1964	226.5	195.0	136.7	92.0	75.3	839.8	790.4	473.2	
1965	226.1	197.3	134.9	88.8	77.1	1069.0	1035.9	477.2	
1966	190.9	160.8	143.2	87.4	72.2	484.8	547.6	477.0	
1967	284.6	231.7	140.6	98.2	74.0	NA	968.3	477.0	
1968	350.2	302.2	145.5	98.5	74.6	NA	NA	NA	
1969	199.7	175.9	147.1	97.9	74.0	NA	NA	NA	
1970	229.7	210.1	145.4	99.7	74.0	1119.1	1049.8	471.8	
1971	168.2	154.4	140.0	99.7	83.3	900.8	854.1	477.0	
1972	227.6	217.7	140.0	104.7	82.0	611.9	558.2	475.6	
1973	156.1	145.7	140.0	96.9	82.0	622.4	609.7	480.2	
1974	161.2	144.5	130.2	94.3	81.1	556.1	500.0	413.7	
1975	231.3	203.5	140.0	98.8	82.0	543.8	531.1	439.9	
1976	373.1	292.7	147.5	100.0	85.9	866.9	814.1	477.0	
1977	345.0	333.8	151.3	105.5	93.3	1822.8	1761.8	553.4	650.0
1978	255.3	218.4	140.0	108.6	93.6	828.8	809.1	477.0	595.0
1979	151.1	153.1	140.0	112.7	86.0	354.3	365.1	392.8	408.1
1980	164.5	168.7	148.4	89.5	80.4	249.7	439.7	240.8	201.4
1981	473.6	489.3	163.2	89.5	86.2	1431.1	1568.4	500.8	803.8
1982	245.4	228.9	156.8	95.5	90.3	851.4	1164.6	477.0	634.0
1983	361.8	317.8	155.5	96.6	90.3	677.7	680.9	510.5	634.7
1984	179.3	179.6	144.7	89.7	80.1	503.3	548.4	433.4	482.4
1985	352.9	307.5	166.3	81.1	82.0	641.4	1064.6	477.0	590.3
1986	165.8	179.2	156.1	89.0	89.1	543.9	562.9	477.0	513.5
1987	419.6	322.0	164.4	93.1	89.3	1475.2	1415.4	477.0	667.0
1988	226.9	199.4	172.3	85.5	89.7	855.8	962.9	477.0	536.5
1989	298.6	240.2	169.8	97.1	93.7	957.9	1296.4	477.0	593.2
1990	242.7	175.5	176.0	99.2	95.6	747.0		493.2	625.0

Table 7 : Annual Maximum Discharge Summary for the Juba River

Year	Luuq	Bardheere	Jammame	Marere
Maximum (m^3/s)	1,823	1,762	553	804
Minimum (m^3/s)	250	365	241	201
Std. Deviation (m^3/s)	335	367	54	141
CV	18%	21%	10%	18%

Table 8 : Annual Maximum Discharge Summary for the Shabelle River

Year	Belet Weyne	Bulo Burti	Mahadey Weyne	Afgoi	Awdegle
Maximum (m^3/s)	473.6	489.3	176	112.7	95.6
Minimum (m^3/s)	138.5	144.5	130.2	81.1	72.2
Std. Deviation (m^3/s)	88.6	78.3	12.4	7.0	7.1
CV	19%	16%	7%	6%	7%

High flows in the Juba and Shabelle rivers are known to cause flooding problems in the two river basins. Since bank full conditions occurred during high flow periods as the two rivers flow downstream, the maximum flood values observed in the lower reaches of the rivers were limited to the bank full values only. Hence, flood frequency analyses were more appropriate for the locations in the upstream reaches only. For estimation of the design flood values in the lower reaches, it would be more appropriate to use flood routing methods like the one carried out in Section 3.6 (River Analysis) later. The flood estimates based on Gumbel distribution[9] for the two rivers are summarized in **Table 9**. It can be seen that the design flood values in Juba are more than that in Shabelle River.

Table 9 : Flood Frequency Analysis (m^3/s) for Selected Stations in Juba and Shabelle

Location	Area (Km^2)	Return Periods (years)							
		2	5	10	20	50	100	500	1000
Juba at Luuq	168,737	783	1,117	1,338	1,550	1,825	2,031	2,506	2,710
Shabelle at Belet Weyne	193,224	249	337	395	450	522	576	701	754

The flood volume is not very big compared to the catchment areas of the two rivers. However, various natural and man-made causes have aggravated the flood problems in the two river basins as mentioned earlier in chapter one.

3.4 Bank Full Conditions

In the case of the Juba and Shabelle Rivers, it is important to note that the floods in the lower reaches have been attenuated (peaks flattened) due to over bank spillage, breaching of river banks for irrigation purposes and over-topping of them to flood the areas in the surrounding.
Figure **14** and

[9] The Gumbel Distribution was found to be the best fit distribution among the distributions tested during this study.

Figure **15** present the annual hydrograph for typical high and low flow years. It is evident from the hydrographs that the downstream locations of the rivers are prone to bank-full conditions where the flows spill over to the adjoining areas. From the hydrographs, the following bank full discharges were estimated.

Bank Full Discharge

Juba River at Jamame	500 m^3/s
Shabelle River at Mahadey Weyne	160 m^3/s
Shabelle River at Afgoi	90 m^3/s
Shabelle River at Audegle	90 m^3/s

These conditions are also verified by the river analysis using the newly acquired digital terrain data from the aerial photography data described in Section 3.6.

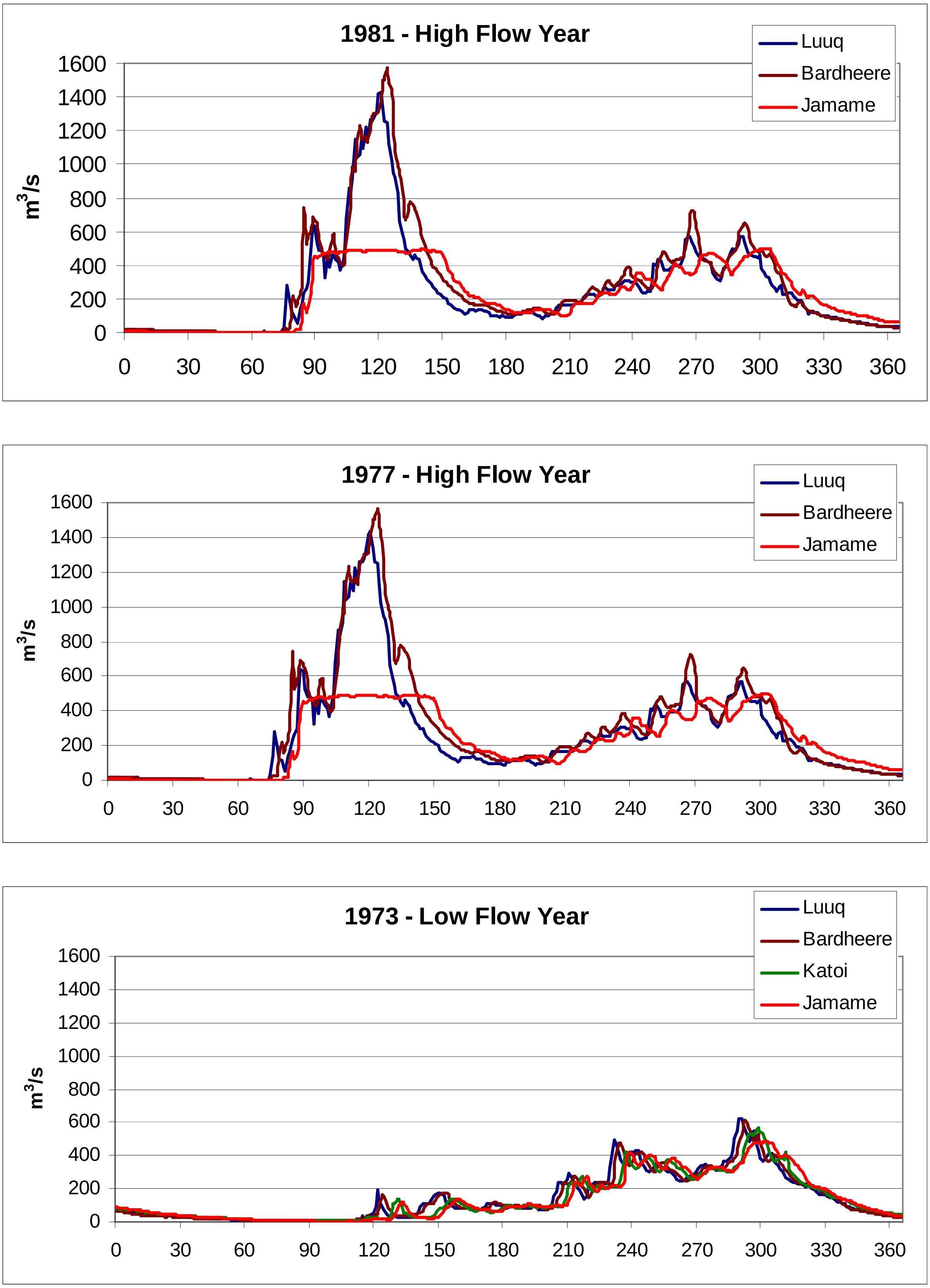


Figure 14 : Flow Hydrographs for Selected Years for the Juba River

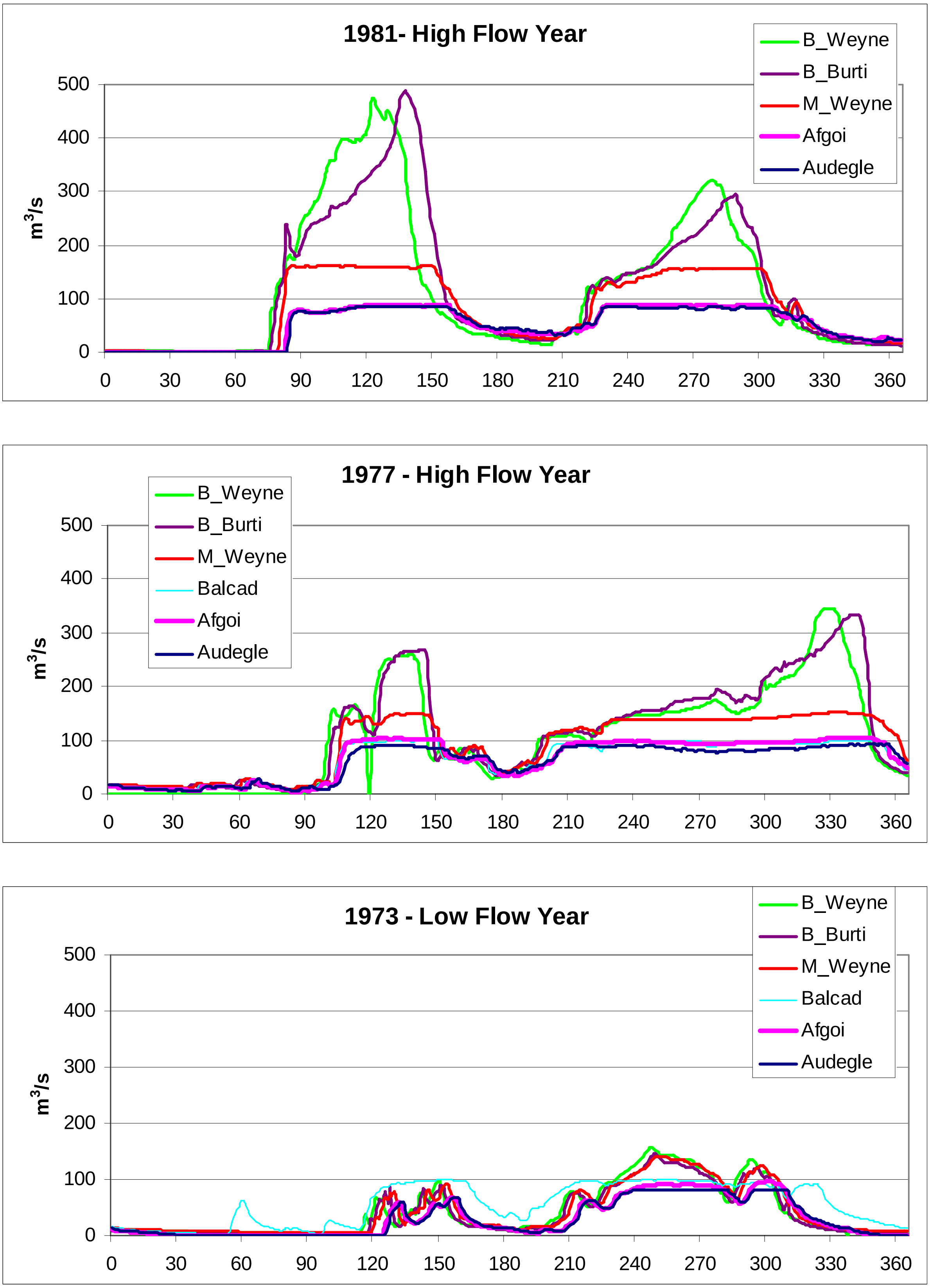


Figure 15 : Flow Hydrographs for Selected Years for the Shabelle River

3.5 River Geomorphology

The cross-sectional transects along the Juba and Shabelle Rivers within Somalia are presented in Figure 16 and Figure 18 each followed by the river cross sections at the transects. These have been derived from the digital terrain models (DTMs) derived from the aerial photography carried out in January 2008. It can clearly be seen that both rivers are protected by dykes (embankments) running along the rivers to protect the adjacent land from flooding. The adjacent areas; cultivated and settlements, especially in the lower stretches of both the rivers are lower than the river channel. The terrain of the two rivers is also interspersed with natural and manmade flood relief and flood retention areas along the rivers. The breaching of the embankments for irrigation in the dry season leads to flooding and spill over of flood water during the wet season. Similarly, the closure of natural flood relief channels and encroachment of flood retention areas and flood plains have led to further aggravation of floods and inundation of adjacent areas in the downstream areas.

The hydraulic infrastructure, including the barrages along the rivers, primary irrigation canals conveying water to irrigations, off-stream reservoirs like the Jowhar off-stream reservoir and other flood relief canals are now mostly out of operation. This has led to rise in the Shabelle River bed level and breaching of embankments at will.

The longitudinal surface water profiles during the time of survey of the two rivers are presented in Figure 17 and Figure 19. The surface water slope along the course is given in Table 10 and Table 11 for the two rivers**.** It can be seen that the average slope in the Juba River is about 1 in 5,194 which is equivalent to 16cm elevation change in 1 Km distance. However, the slope decreases in the downstream stretches. Similarly, for the Shabelle River, the average slope is 1 in 6,803 which is equivalent to 14.6cm elevation change in 1 Km distance.

Table 10 : Profile of Juba River

Chainage (Km)	Elevation (m)	Slope	In m per Km	1 m in Km length
0.0	162.3			
100	142.5	0.000198	0.19807999	5,048
200	119.7	0.000228	0.22755501	4,395
300	98.6	0.000211	0.21131401	4,732
400	76.1	0.000226	0.22552597	4,434
500	60.1	0.000159	0.15915604	6,283
600	42.5	0.000177	0.17663002	5,662
700	27.5	0.000149	0.14946798	6,690
	average	0.000193	0.19253272	5,194

Table 11: Profile of Shabelle River

Chainage (Km)	Elevation (m)	Slope	In m per Km	1 m in Km length
0	185.8			
100	166.0	0.000198	0.198119	5,047
200	141.4	0.000246	0.246022	4,065
300	117.6	0.000238	0.237892	4,204
400	106.4	0.000112	0.112398	8,897

Chainage (Km)	Elevation (m)	Slope	In m per Km	1 m in Km length
500	94.8	0.000116	0.115601	8,650
600	78.3	0.000165	0.165099	6,057
700	70.6	7.73E-05	0.077296	12,937
800	56.3	0.000142	0.142448	7,020
900	46.3	0.0001	0.100171	9,983
1000	38.8	7.48E-05	0.074822	13,365
	average	0.000147	0.146987	6,803

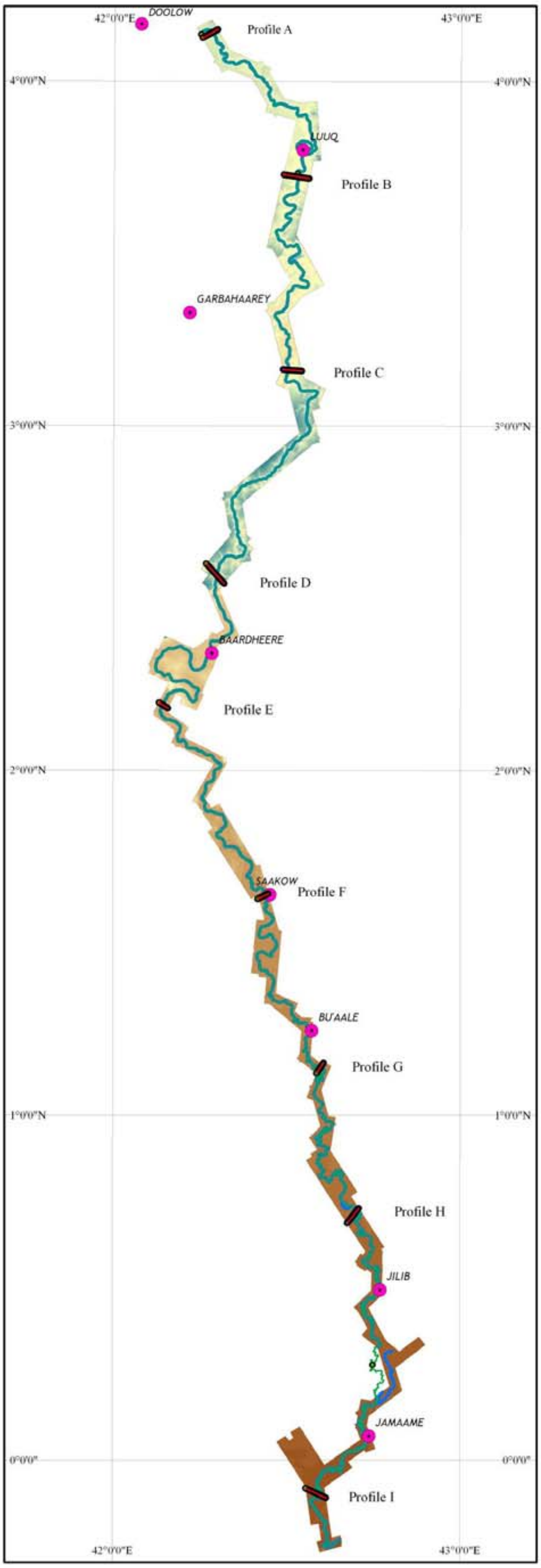
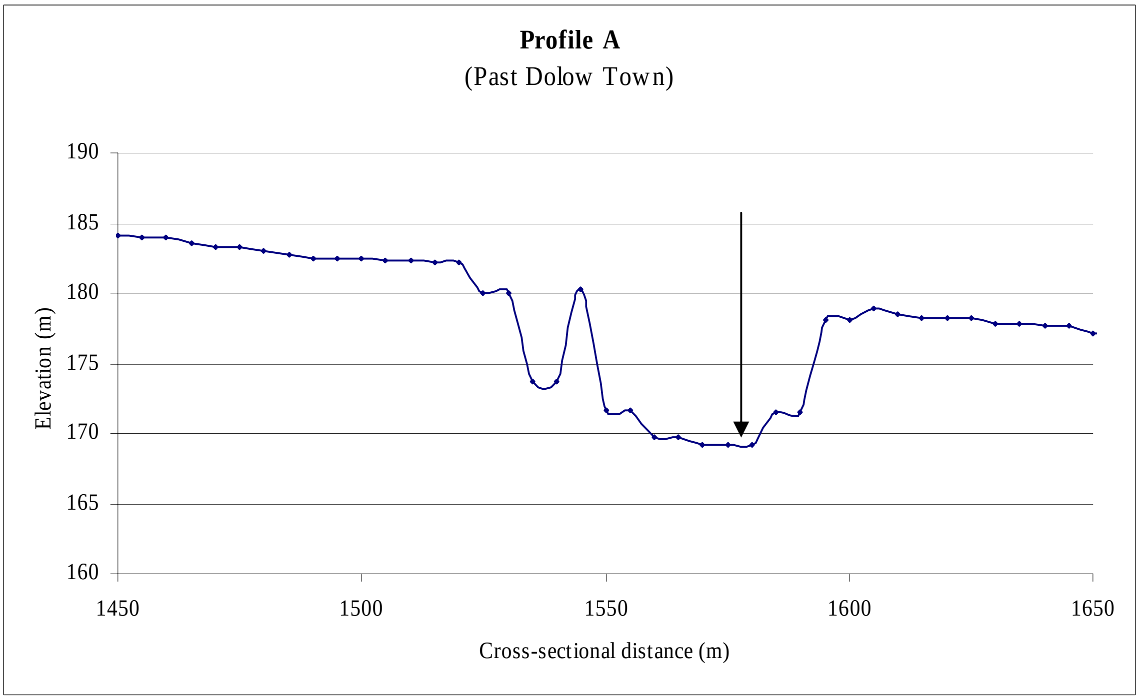
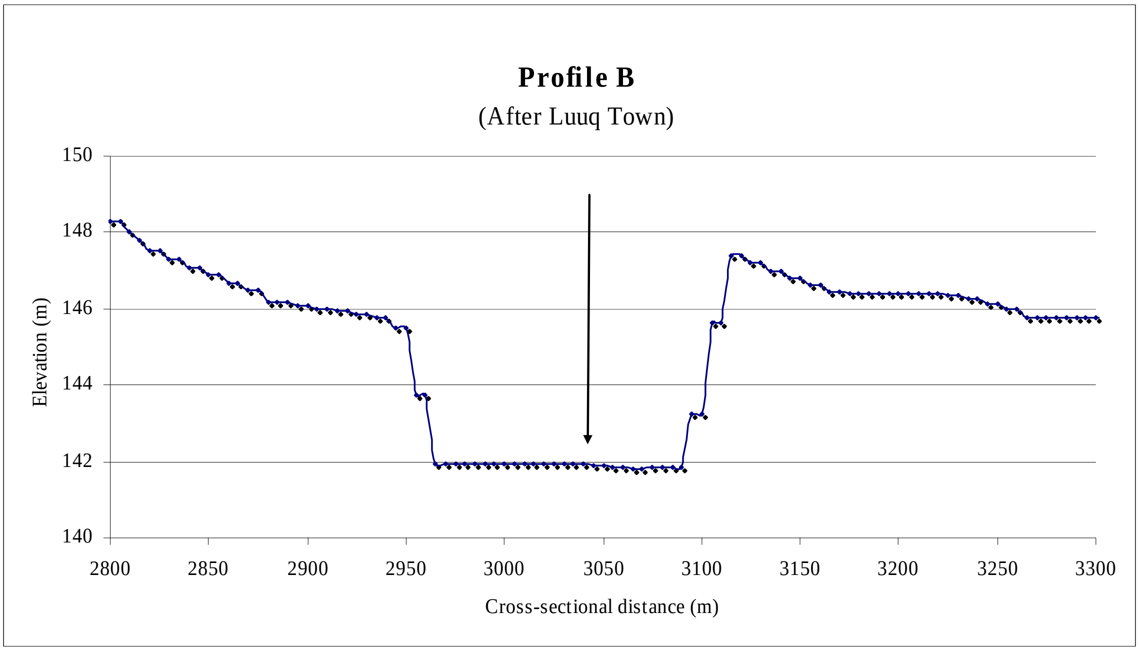


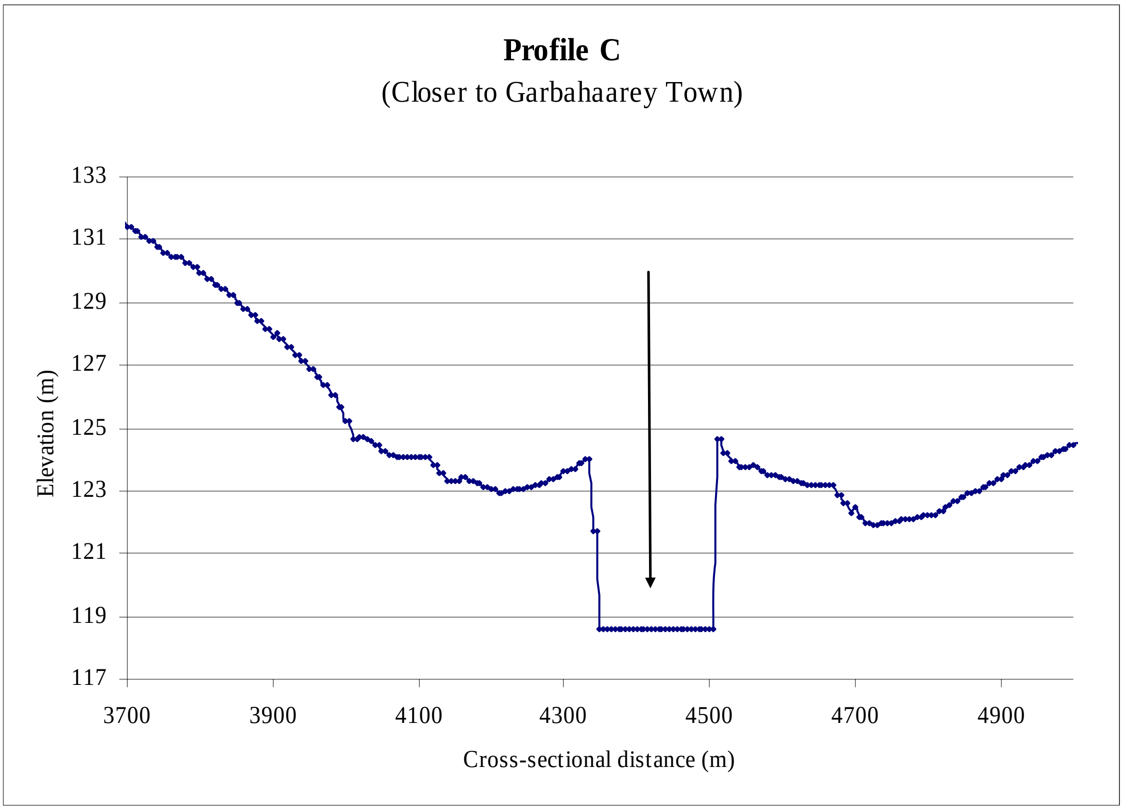
Figure 16 : Cross-sectional Transects along the Juba River (within Somalia)
(Detailed cross sections at the transects are given below)

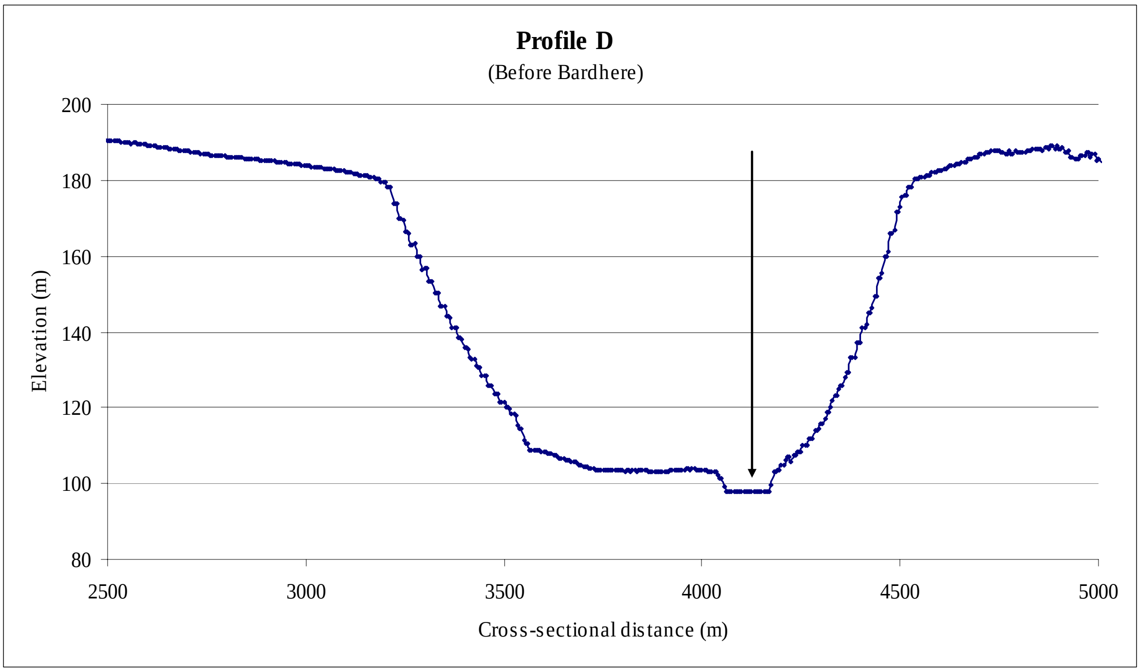


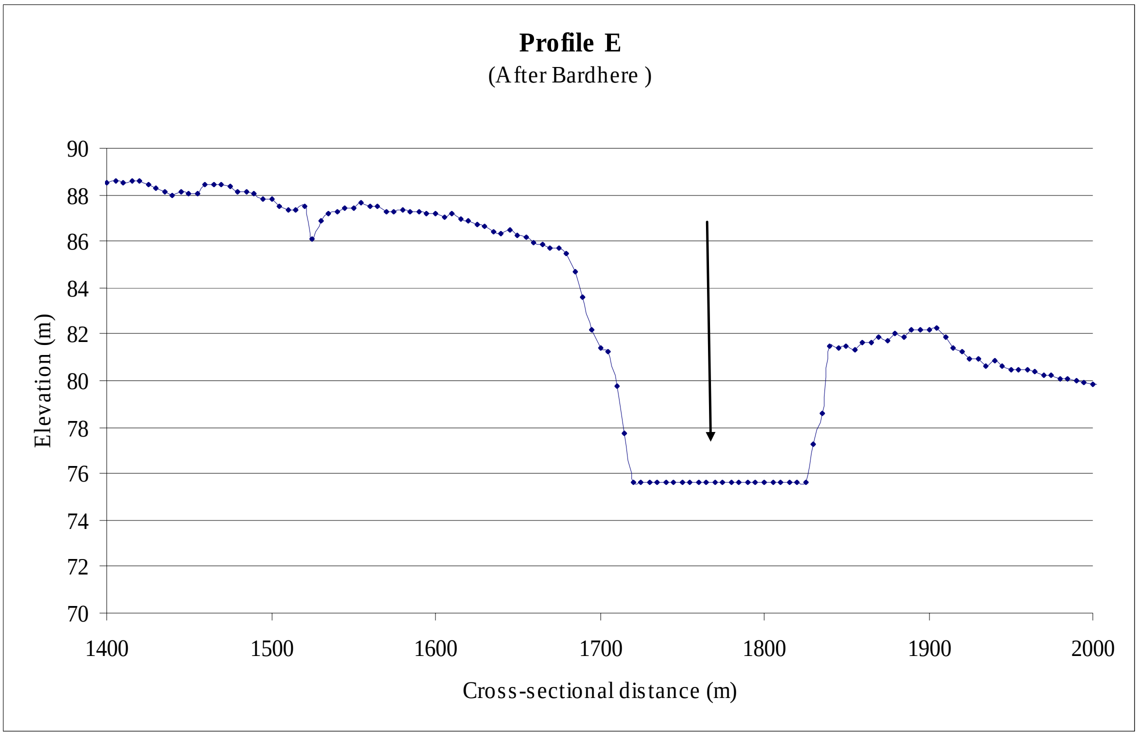
Profile A
(Past Dolow Town)
190
185
180
175
170
165
160
Elevation (m)
1450
1500
1550
1600
1650
Cross-sectional distance (m)

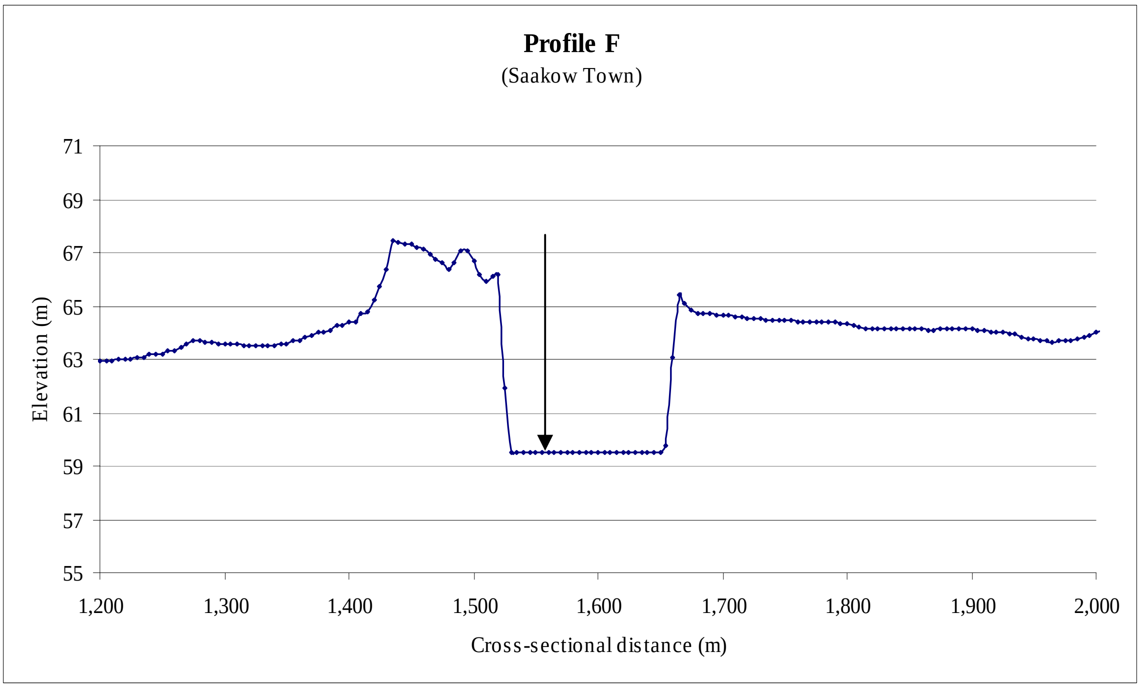


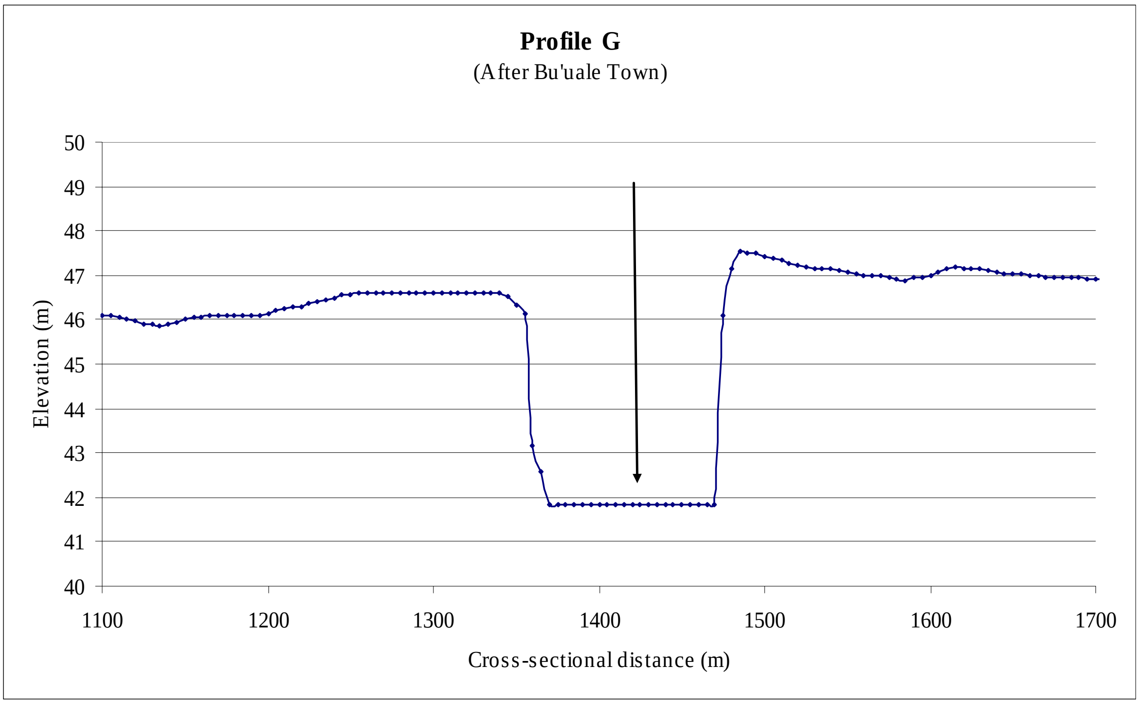
Profile B
(After Luuq Town)
150
148
146
144
142
140
Elevation (m)
2800
2850
2900
2950
3000
3050
3100
3150
3200
3250
3300
Cross-sectional distance (m)


Profile C
(Closer to Garbahaarey Town)
133
131
129
127
125
123
121
119
117
Elevation (m)
3700
3900
4100
4300
4500
4700
4900
Cross-sectional distance (m)

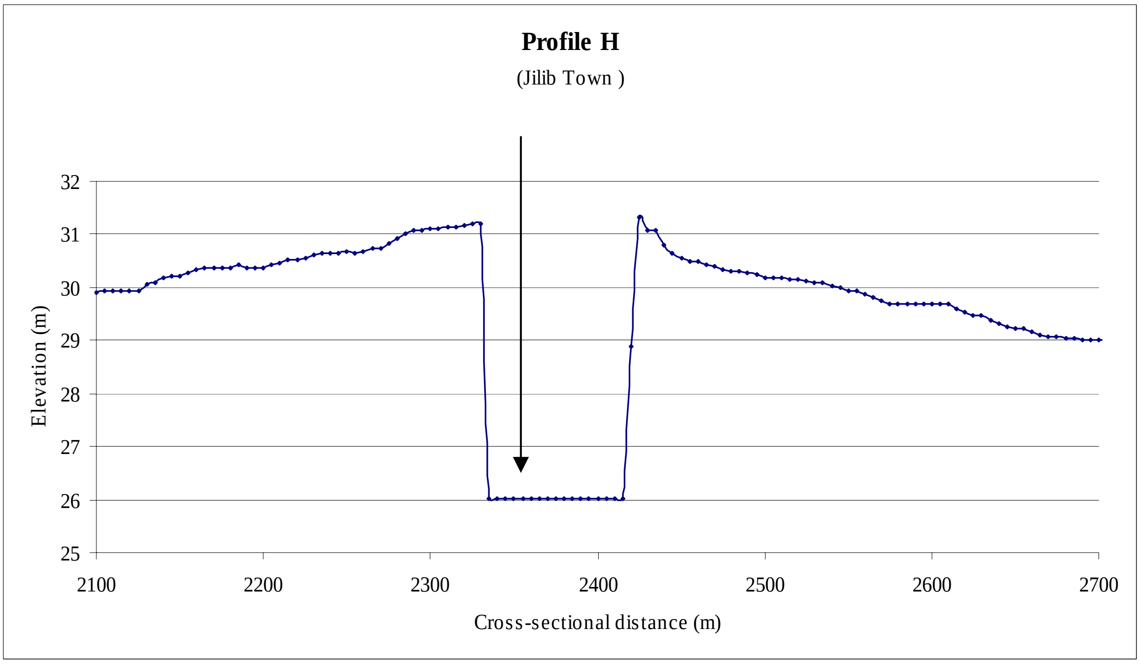

Profile D
(Before Bardhere)
200
180
160
140
120
100
80
Elevation (m)
2500
3000
3500
4000
4500
5000
Cross-sectional distance (m)


Profile E
(After Bardhere)
90
88
86
84
82
80
78
76
74
72
70
Elevation (m)
1400
1500
1600
1700
1800
1900
2000
Cross-sectional distance (m)

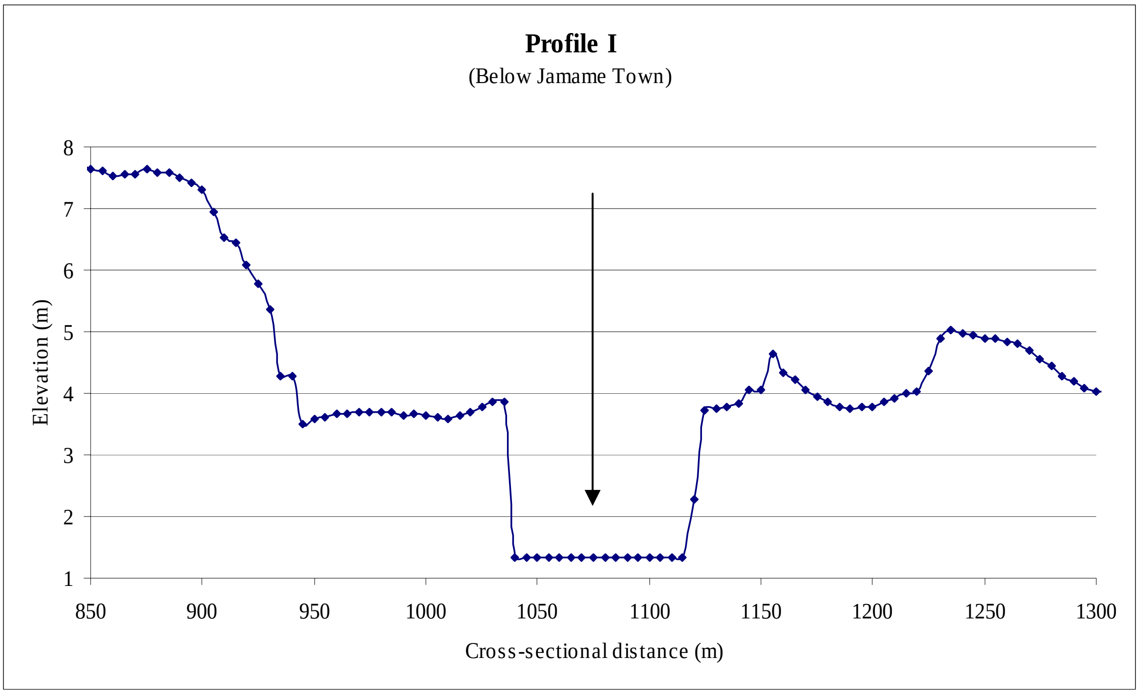

Profile F
(Saakow Town)
71
69
67
65
63
61
59
57
55
Elevation (m)
1,200
1,300
1,400
1,500
1,600
1,700
1,800
1,900
2,000
Cross-sectional distance (m)



Profile G
(After Bu'uale Town)
Elevation (m)
50
49
48
47
46
45
44
43
42
41
40
1100
1200
1300
1400
1500
1600
1700
Cross-sectional distance (m)



Profile H
(Jilib Town)
Elevation (m)
32
31
30
29
28
27
26
25
2100
2200
2300
2400
2500
2600
2700
Cross-sectional distance (m)



Profile I
(Below Jamame Town)
Elevation (m)
8
7
6
5
4
3
2
1
850
900
950
1000
1050
1100
1150
1200
1250
1300
Cross-sectional distance (m)

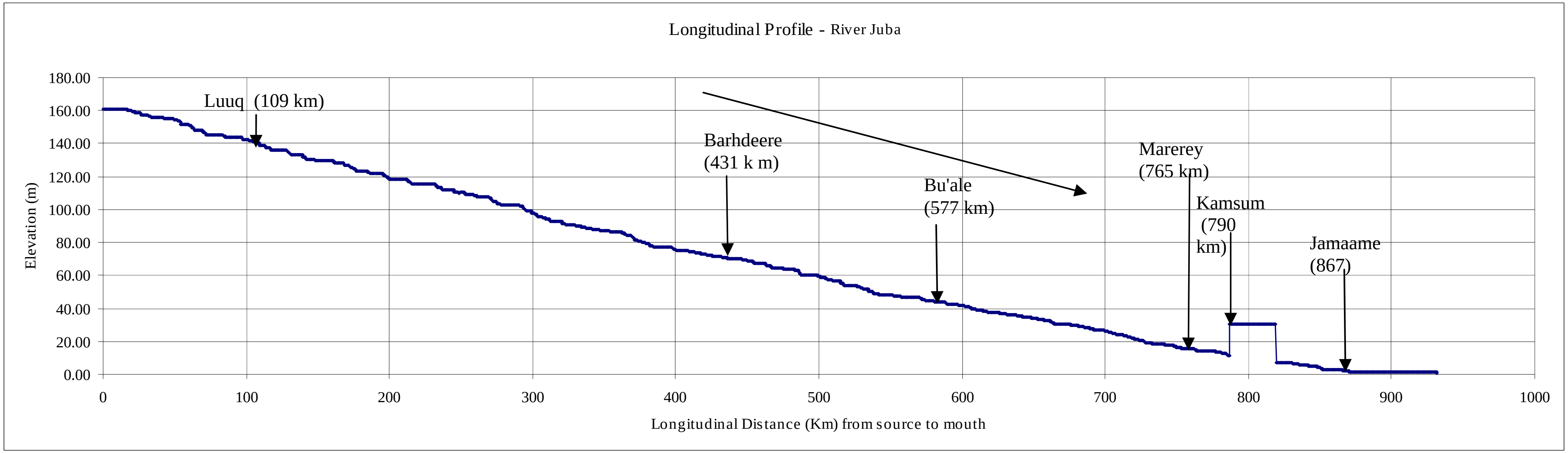


Figure 17 : Longitudinal Profile of the Juba River in Somalia[10]

[10] Note: the break on the profile around 800 Km is due to an error in covering the river course in the region during the survey. This is due to the river shift in the lower stretch

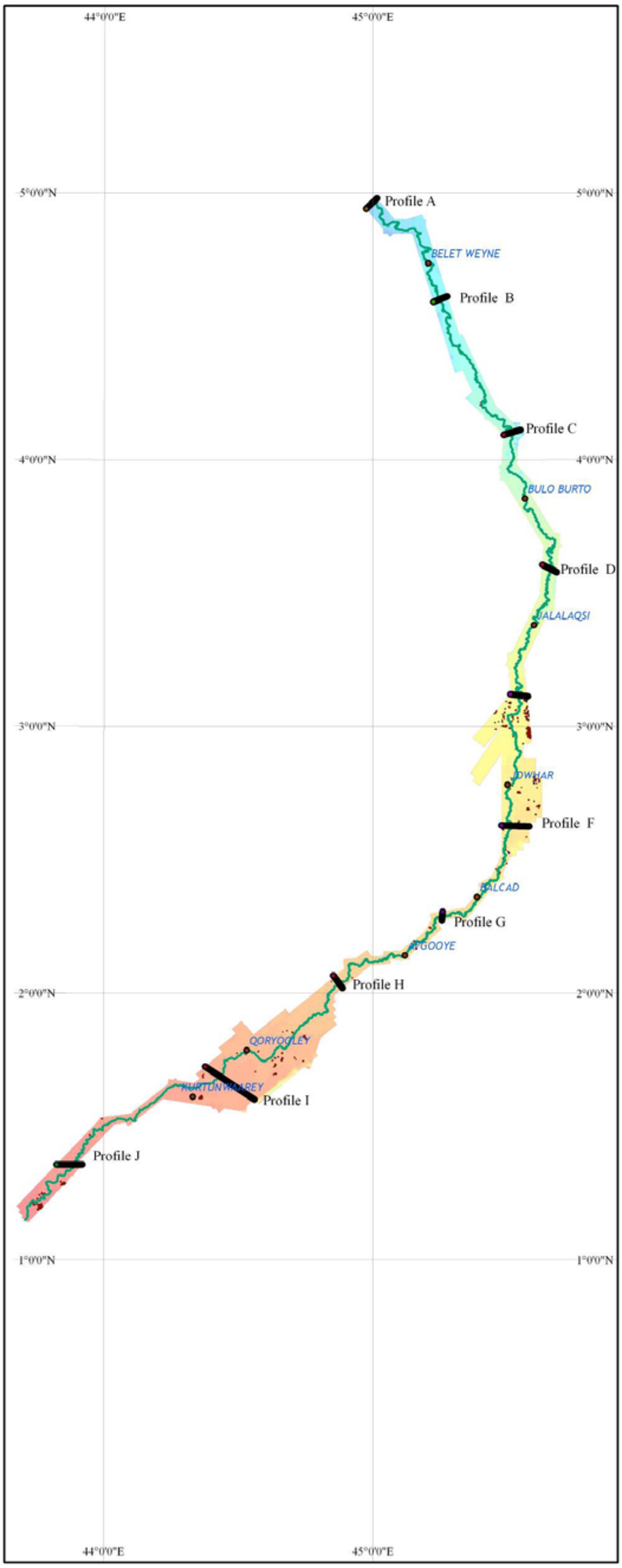
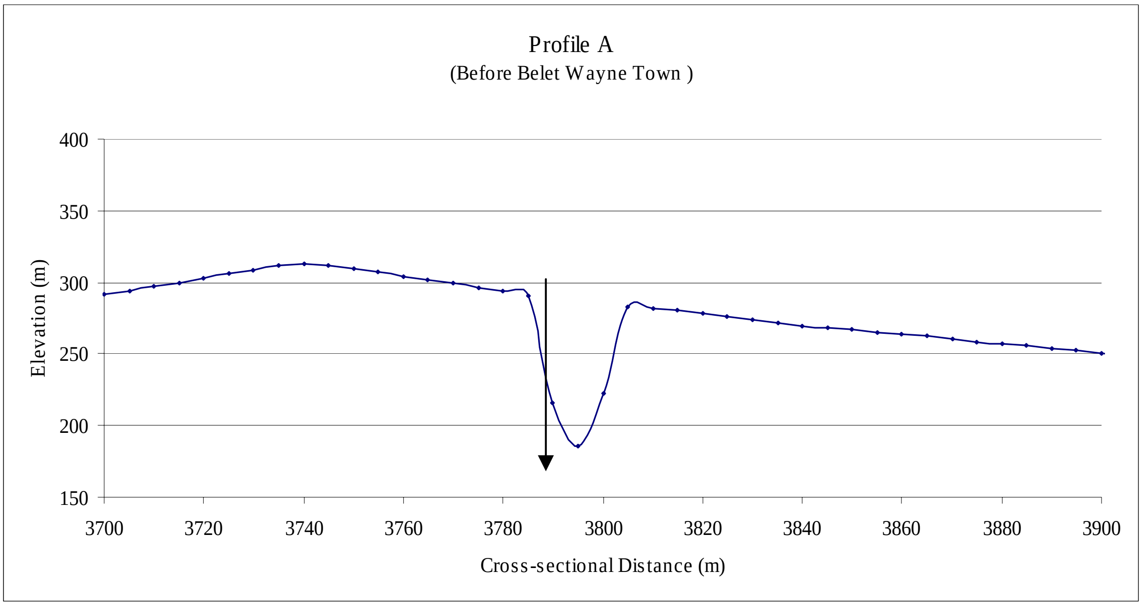
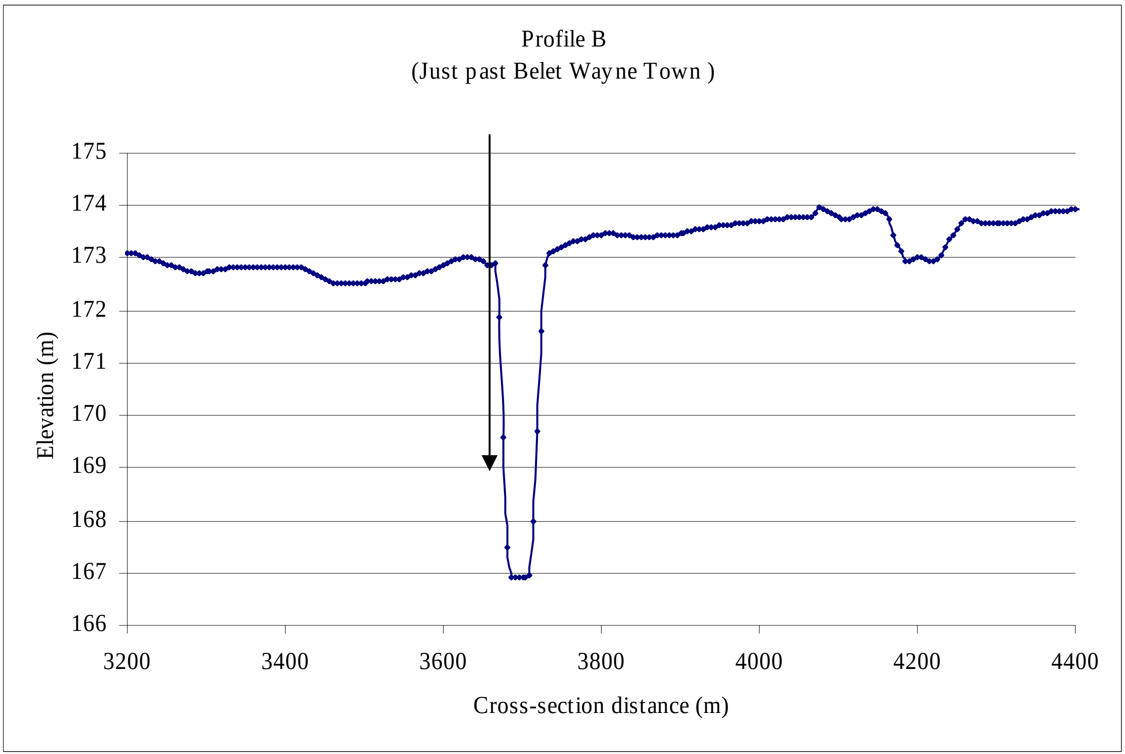
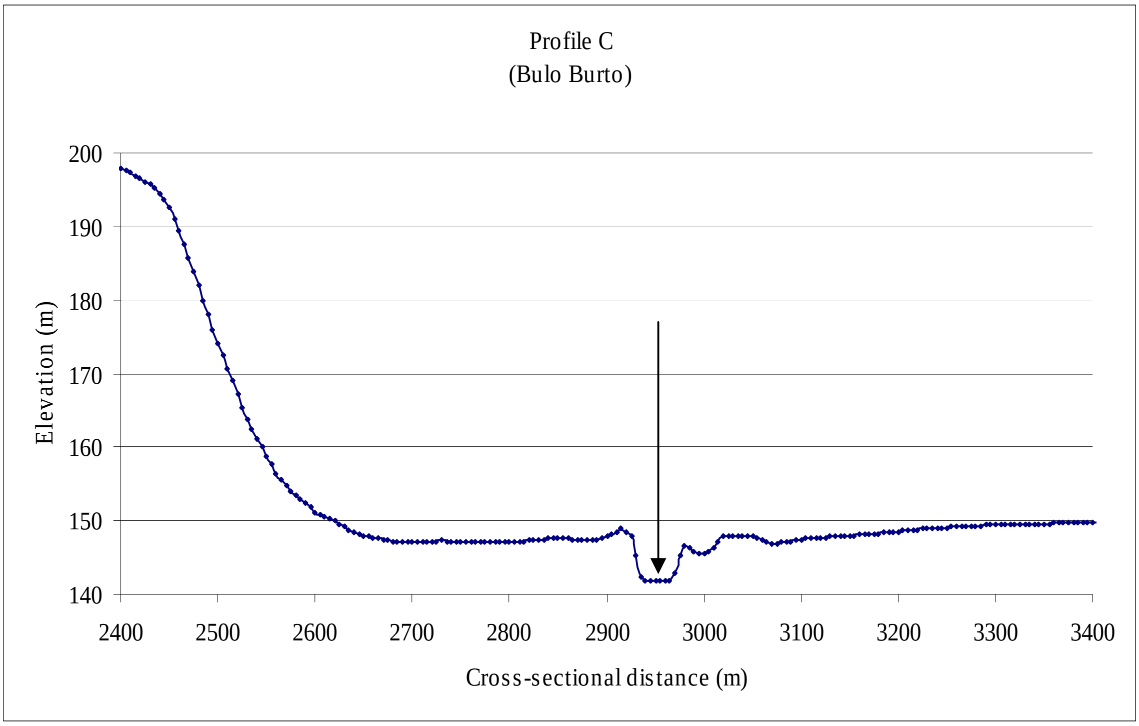
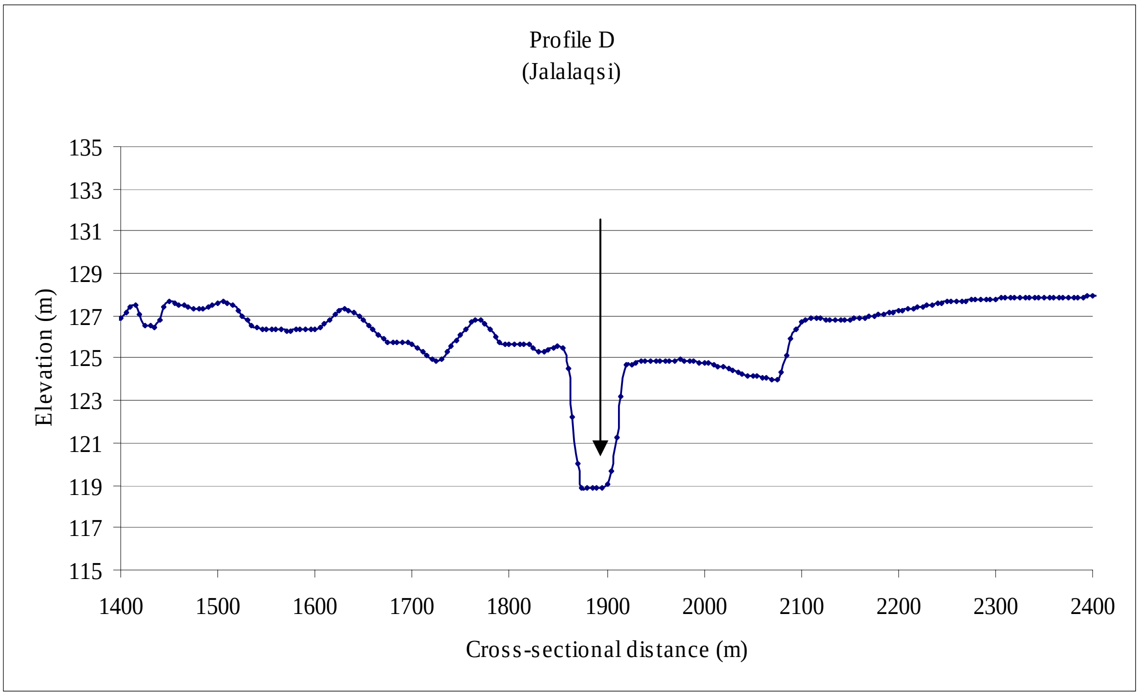


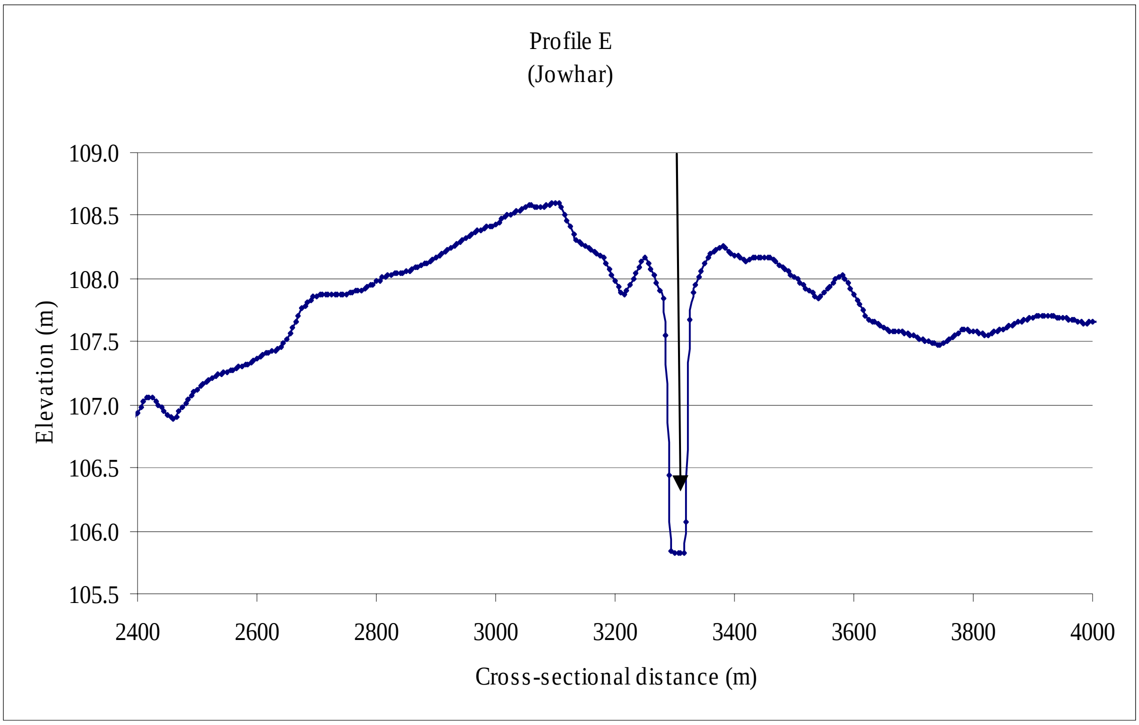
Figure 18 : Cross-sectional Transects along the Shabelle River (within Somalia)
(Detailed cross sections at the transects are given below)


Profile A
(Before Belet Wayne Town)
Elevation (m)
400
350
300
250
200
150
3700
3720
3740
3760
3780
3800
3820
3840
3860
3880
3900
Cross-sectional Distance (m)

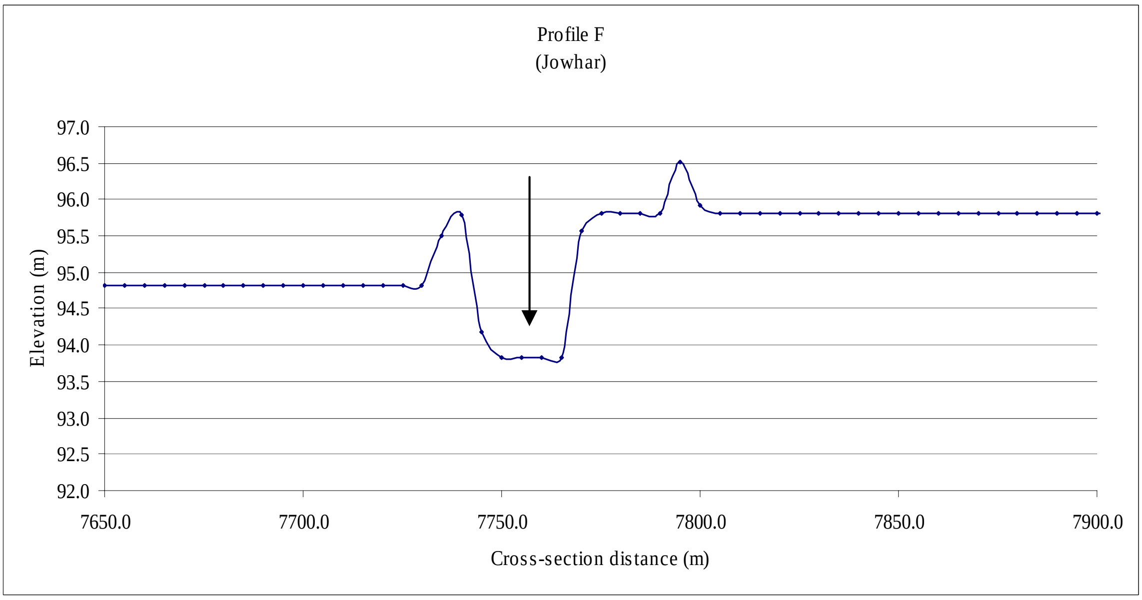

Profile B
(Just past Belet Wayne Town)
Elevation (m)
175
174
173
172
171
170
169
168
167
166
3200
3400
3600
3800
4000
4200
4400
Cross-section distance (m)


Profile C
(Bulo Burto)
Elevation (m)
200
190
180
170
160
150
140
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
Cross-sectional distance (m)

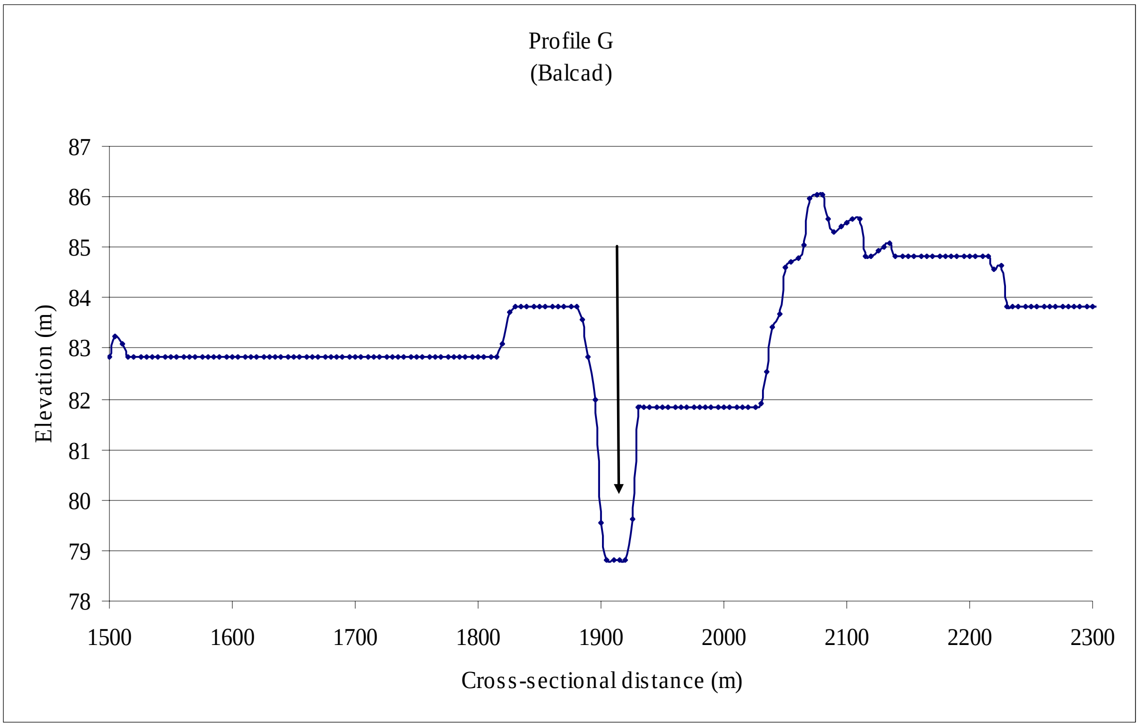

Profile D
(Jalalaqsi)
Elevation (m)
135
133
131
129
127
125
123
121
119
117
115
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
Cross-sectional distance (m)

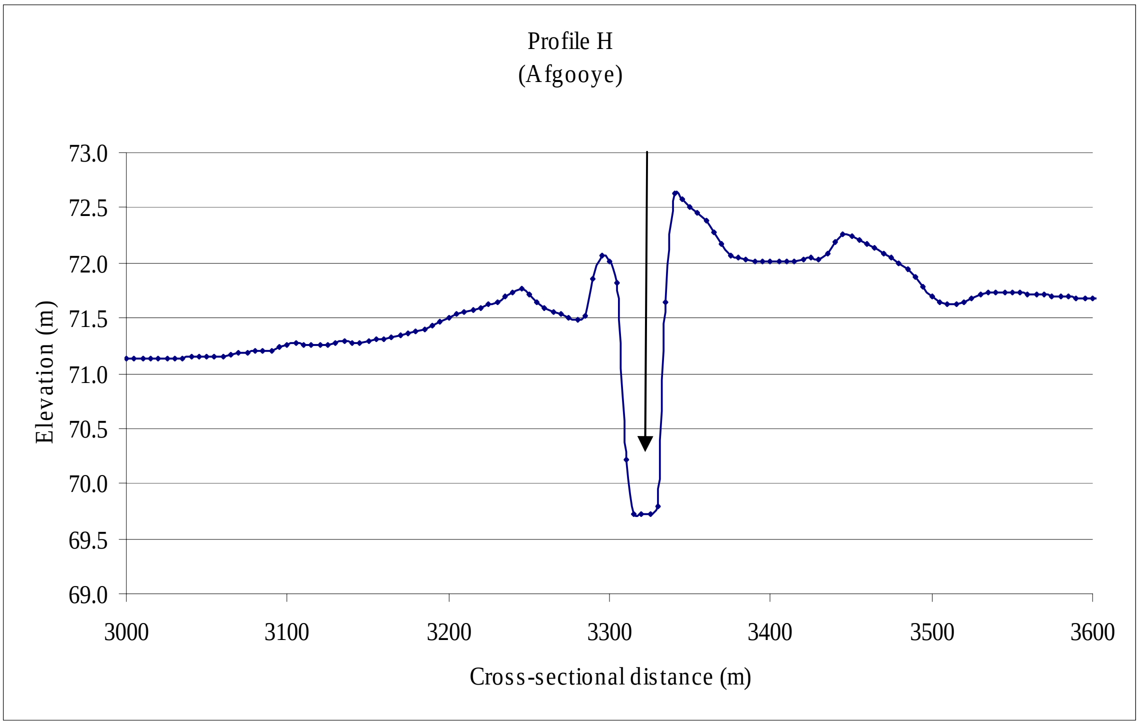


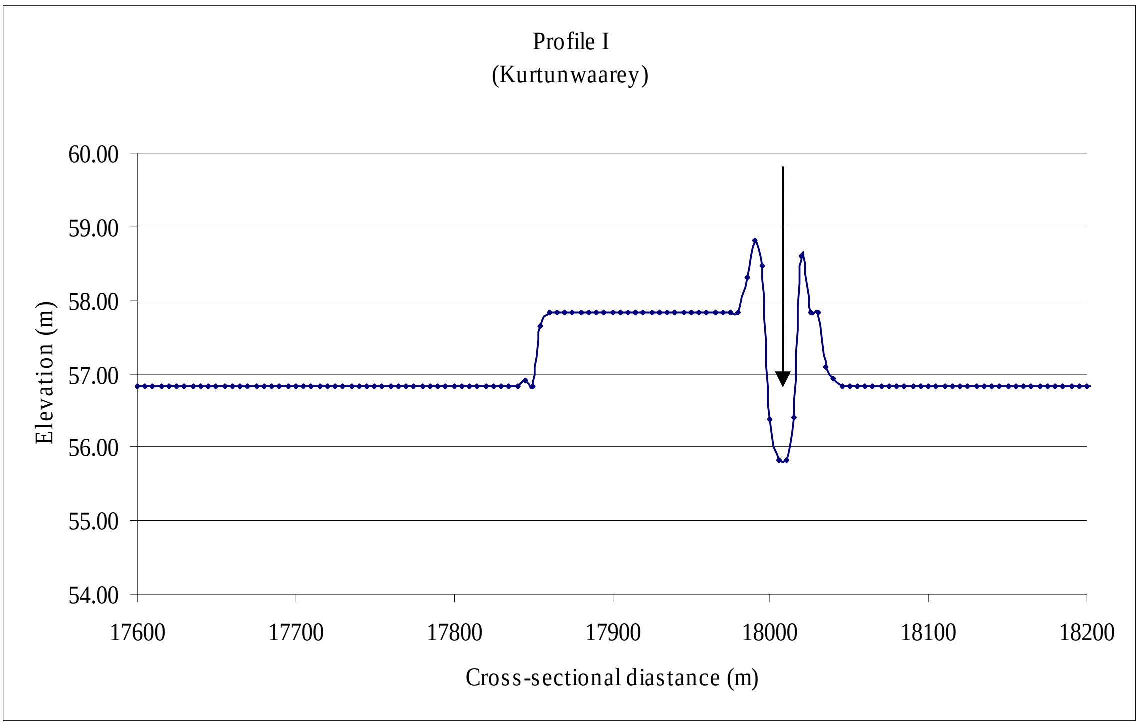
Profile E
(Jowhar)
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
Elevation (m)
2400
2600
2800
3000
3200
3400
3600
3800
4000
Cross-sectional distance (m)



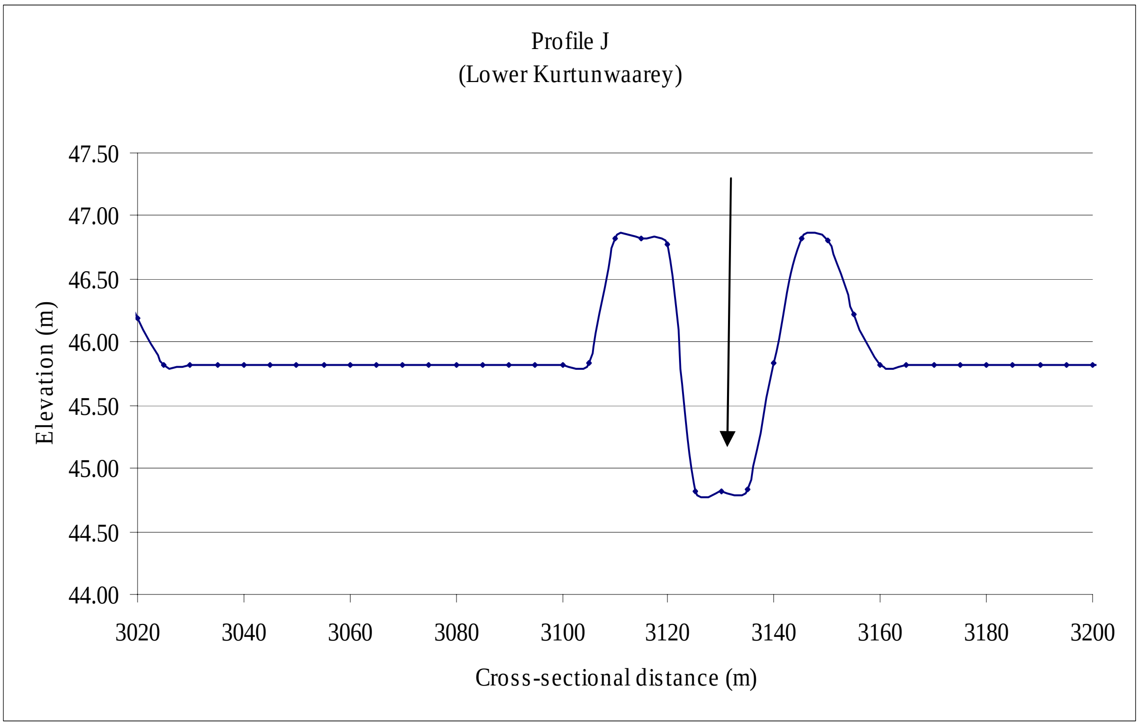
Profile F
(Jowhar)
97.0
96.5
96.0
95.5
95.0
94.5
94.0
93.5
93.0
92.5
92.0
Elevation (m)
7650.0
7700.0
7750.0
7800.0
7850.0
7900.0
Cross-section distance (m)


Profile G
(Balcad)
Elevation (m)
87
86
85
84
83
82
81
80
79
78
1500
1600
1700
1800
1900
2000
2100
2200
2300
Cross-sectional distance (m)


Profile H
(Afgooye)
Elevation (m)
73.0
72.5
72.0
71.5
71.0
70.5
70.0
69.5
69.0
3000
3100
3200
3300
3400
3500
3600
Cross-sectional distance (m)



Profile I
(Kurtunwaarey)
60.00
59.00
58.00
57.00
56.00
55.00
54.00
Elevation (m)
17600
17700
17800
17900
18000
18100
18200
Cross-sectional diastance (m)



Profile J
(Lower Kurtunwaarey)
47.50
47.00
46.50
46.00
45.50
45.00
44.50
44.00
Elevation (m)
3020
3040
3060
3080
3100
3120
3140
3160
3180
3200
Cross-sectional distance (m)

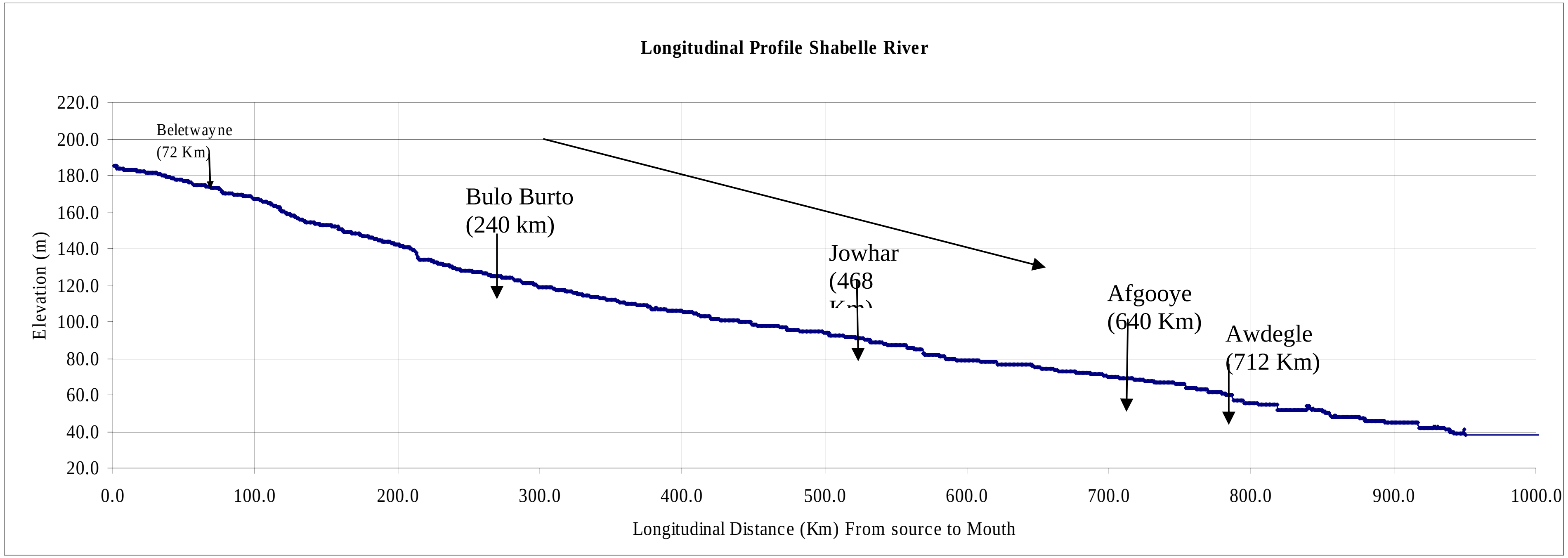


Figure 19 : Longitudinal Profile of the Shabelle River in Somalia

3.6 River Analysis

Hydraulic data including stage-discharge relationships at different locations of the rivers are outdated since it is available for periods prior to 1990. The river control is believed to have changed much between then and now. While SWALIM has started to undertake field work on defining the hydraulic regime including direct discharge measurements using current meters and topographical survey at the gauging station locations, the security situation in Somalia has hampered smooth and reliable field work. Daily staff gauge readings are observed in some of the rehabilitated gauges but development of rating curves to estimate the flows have not been possible due to lack of data.

The availability of 25cm and 50cm vertical accuracy topographical data from the DTMs of the recent aerial photography survey has now given an opportunity to apply river analysis models to study the river hydraulics behaviour. HEC RAS River Analysis Model has been applied to study the flow conditions at different locations of the rivers. HEC GEORAS has been used to pre-process the DTMs to derive the topographical (river cross-sections and hydraulic structures) data required for running HEC RAS model. It is also used to post-process the HEC RAS outputs to delineate flood inundation for different flow conditions. It should however be noted that the HEC RAS model is a one-dimension model and the terrain and hydraulic regime of the Juba and Shabelle Rivers will require the application of 2-D models for accurate flood studies.

In this study, HEC RAS model has been used to study the river hydraulics within the river channel only (within the embankments) with certain assumptions within certain stretches. This will give an estimate of the flow conditions which will lead to over-bank spillages. Although the aerial photography survey was conducted during the dry season, it should be noted that the full under-water cross-sections are not available from the DTMs so certain assumptions (flow depth) have been made to define the under-water cross-sections. This could have been possible provided that LIDAR approach for photography is adopted.

The following analyses were carried out:

1. Estimation of water surface profile for different flow conditions (theoretical rating curves),
2. Estimation of bank full conditions and,
3. Flood inundation studies in some reaches for demonstration purpose only.

It is pointed out here that the theoretical rating curves presented here are based on HEC RAS results. Presence of “loop” rating curves (different water surface elevations for rising and falling flow conditions) could be the case for the Juba and Shabelle rivers. This was however not possible due to lack of discharge measurement in different periods of rising and falling water levels.

3.6.1 Juba River

Three stretches of the Juba River were analysed, near Luuq, Bardheere and Jammme gauging stations and, steady flow conditions for 10 different flows were considered (Table 12). Manning’s roughness coefficient (n) values of 0.02 and 0.025 were assumed for the channel and bank, respectively and, sub-critical flow boundary condition was assumed in the most downstream station.

Table 12: Flow Conditions (Profile) Analysed for the Juba River

Profile	PF1	PF2	PF3	PF4	PF5	PF6	PF7	PF8	PF9	PF10
Flow (m^3/s)	50	100	200	400	600	800	1,000	1,200	1,500	2,000

The results of the different river stretches are presented below.

<u>River Stretch near Luuq</u>

The schematic plot, cross section and theoretical rating curve of a representative station location are presented in Figure 20,
Figure 21 and
Figure 22. It should be noted that the bank full condition of Luuq stretch is for flows above 2000 m^3/s.

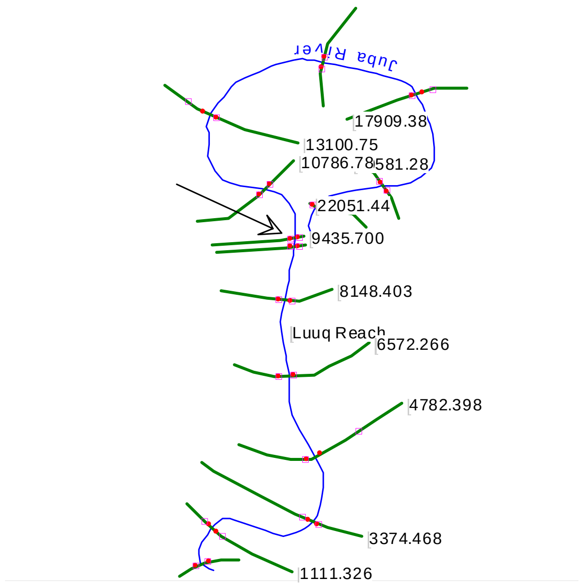


Figure 20: Schematic Plot of the Juba River Stretch near Luuq Gauging Station

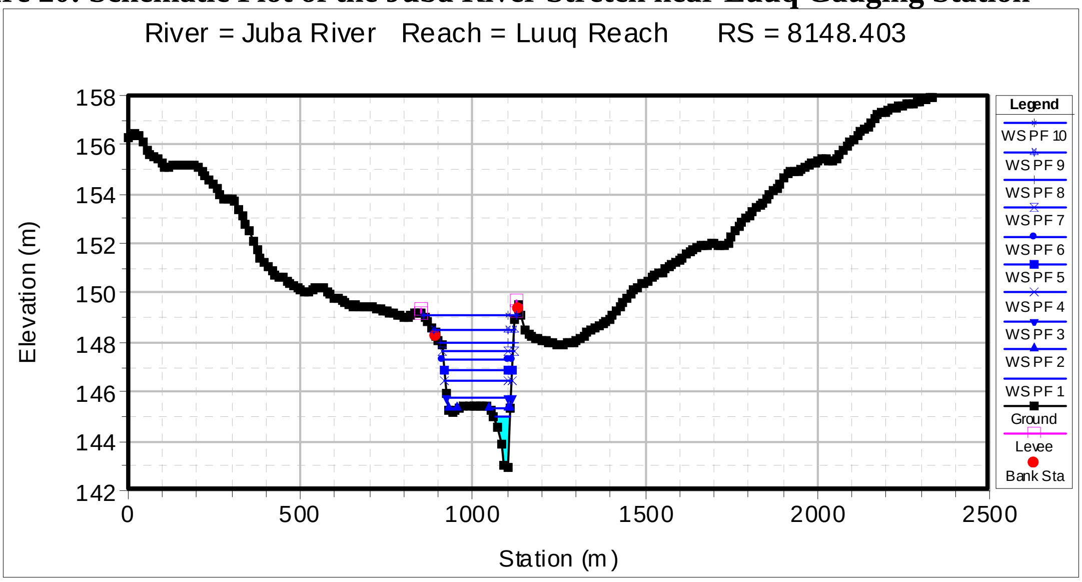
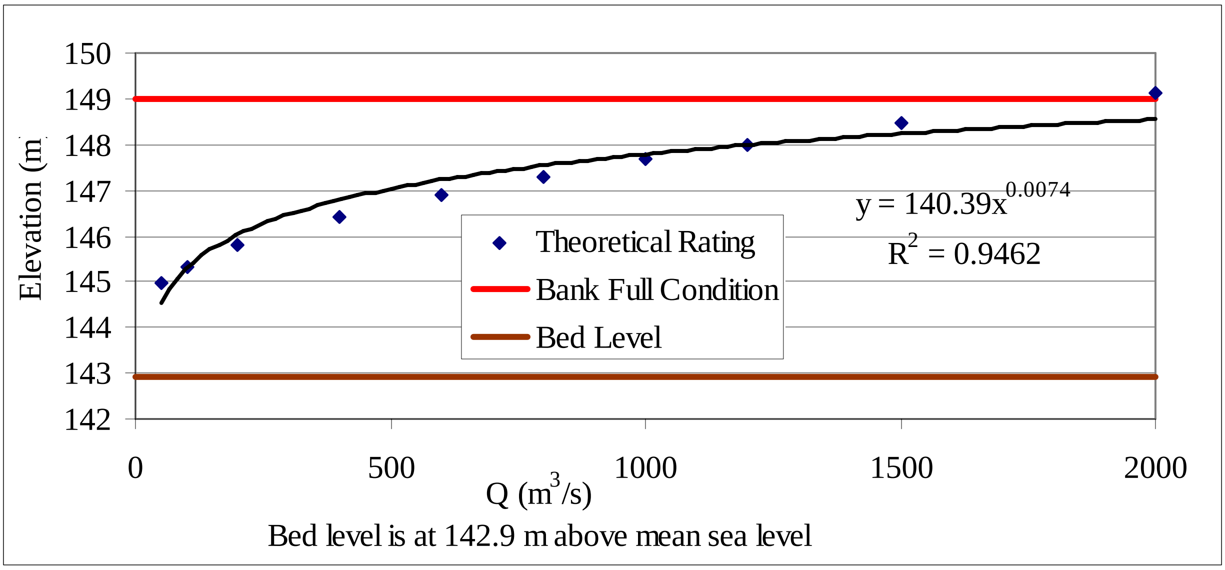


Figure 21: X-section of the Juba River at a representative location near Luuq Stretch



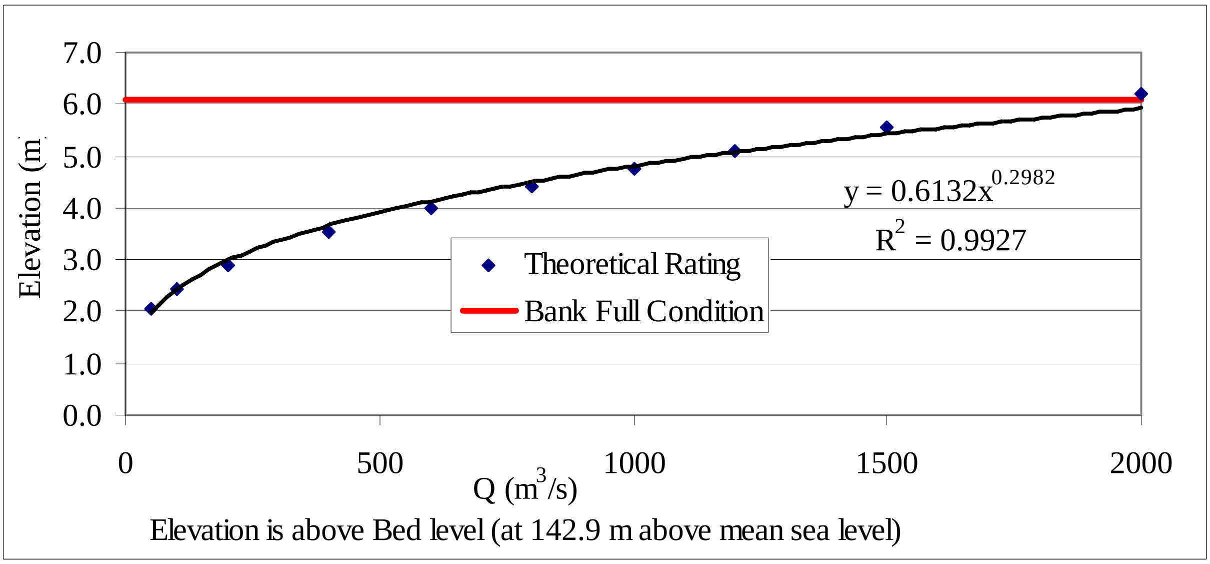


Figure 22: Theoretical Rating Curve of the Juba River at a representative location near Luuq Stretch

<u>River Stretch near Bardheere</u>

The schematic plot, cross section and theoretical rating curve of a representative station location are presented in Figure 29, Figure 30 and Figure 31. It should be noted that the bank full condition of Bardheere stretch is for flows much higher than 2000 m^3/s.

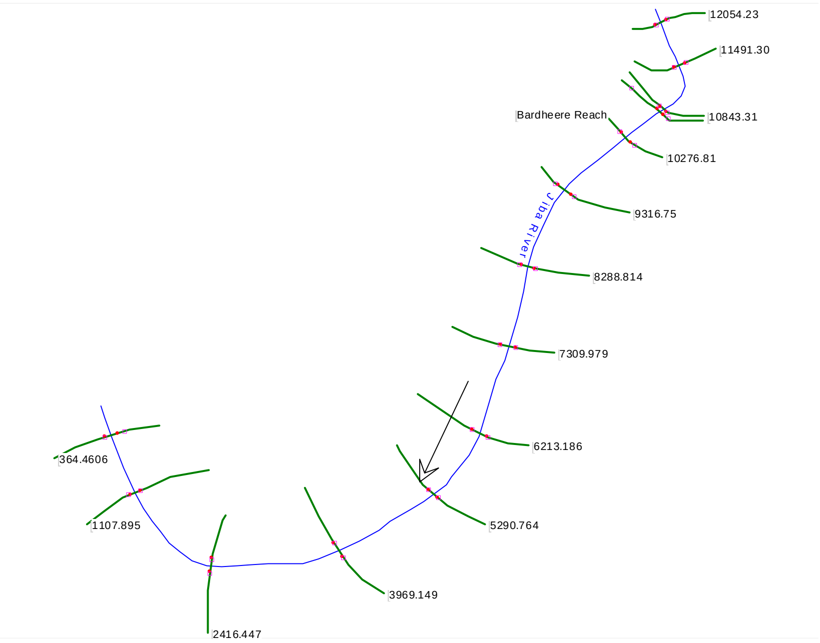


Figure 23: Schematic Plot of the Juba River Stretch near Bardheere Gauging Station

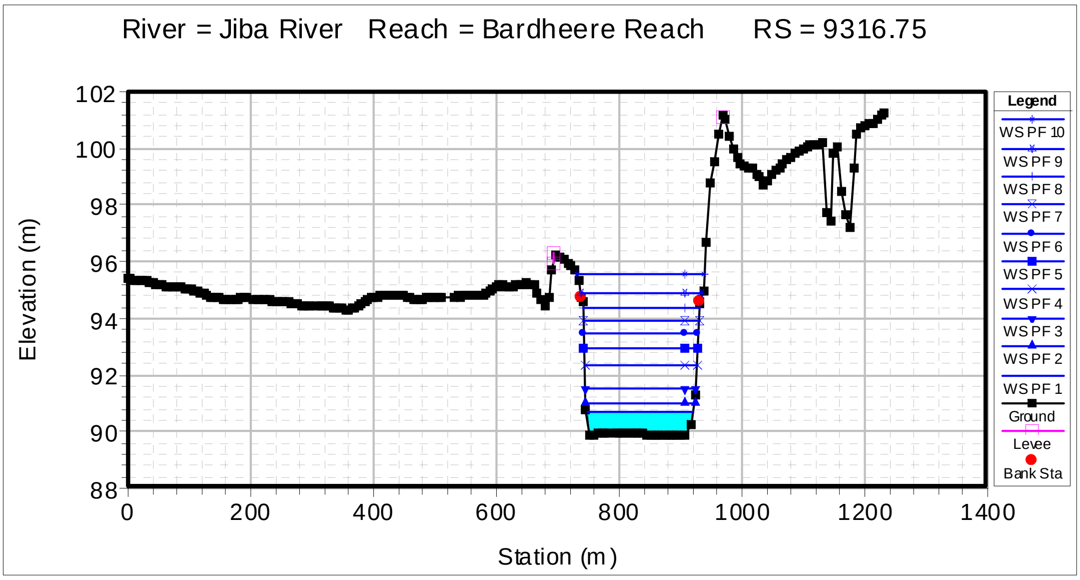
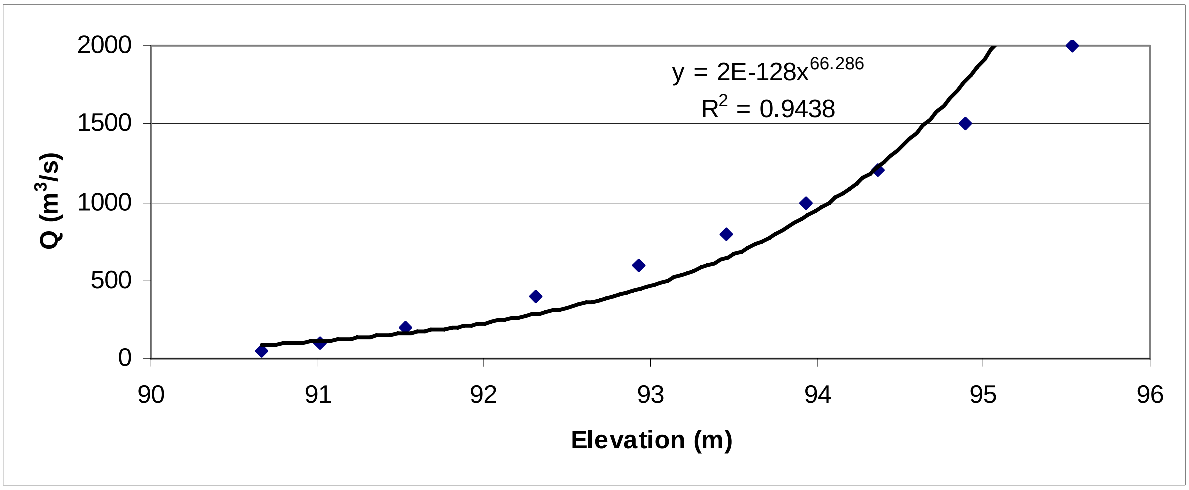


Figure 24: X-section of the Juba River at a representative location near Bardheere Stretch



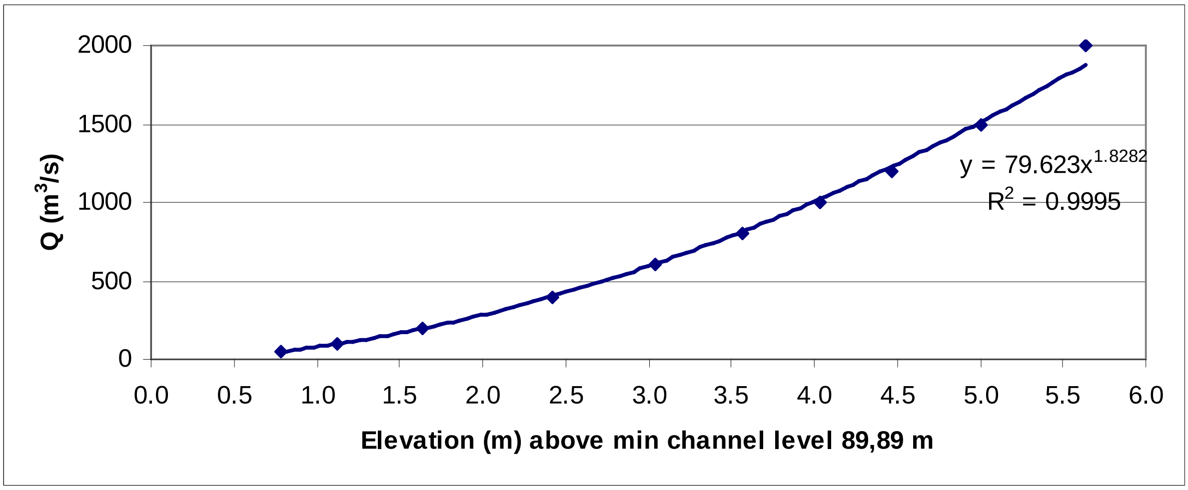


Figure 25: Theoretical Rating Curve of the Juba River at a representative location near Bardheere Stretch

River Stretch near Jammame

The schematic plot, cross section and theoretical rating curve of a representative station location are presented in
Figure 26,
Figure 27 and Figure 28. It should be noted that the bank full condition of Jammame stretch is a little more than 500 m3/s.

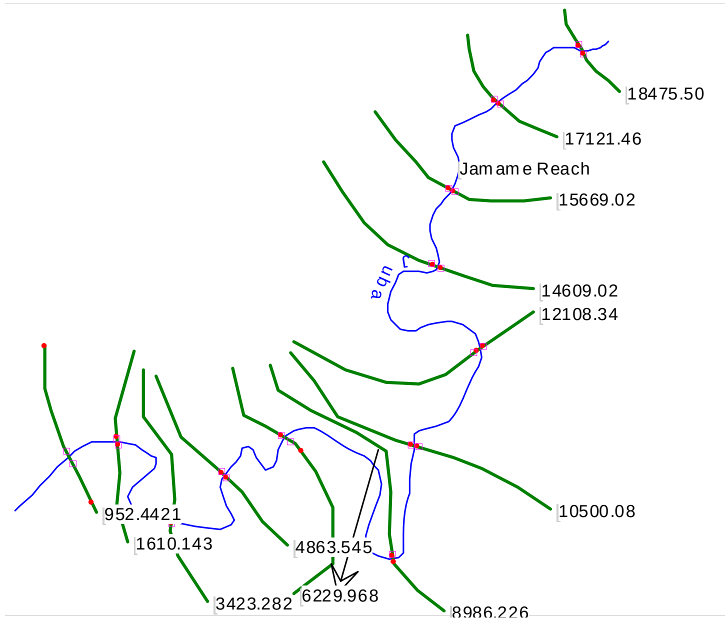


Figure 26: Schematic Plot of the Juba River Stretch near Jammame Gauging Station

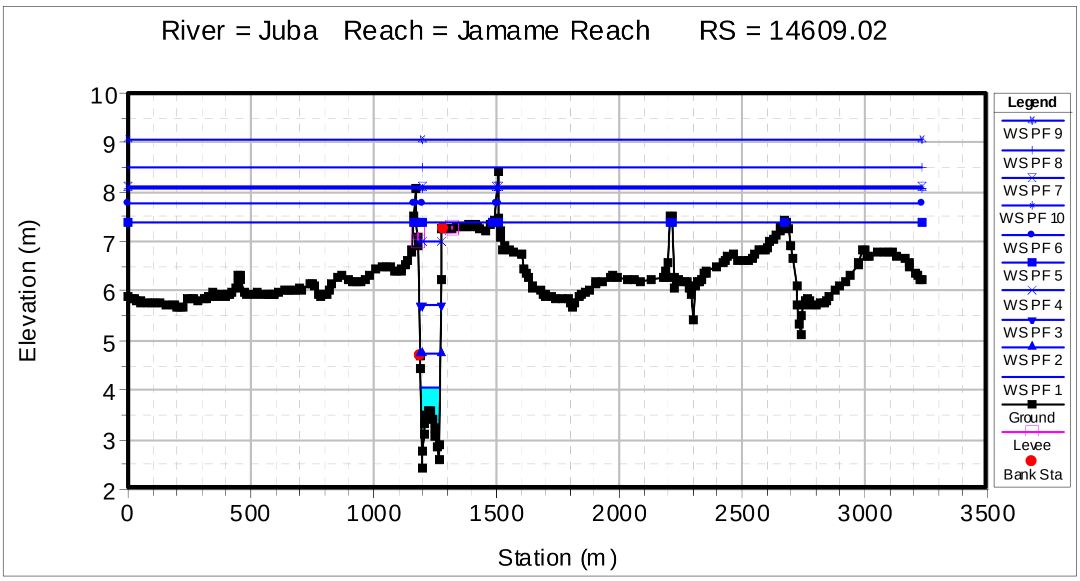
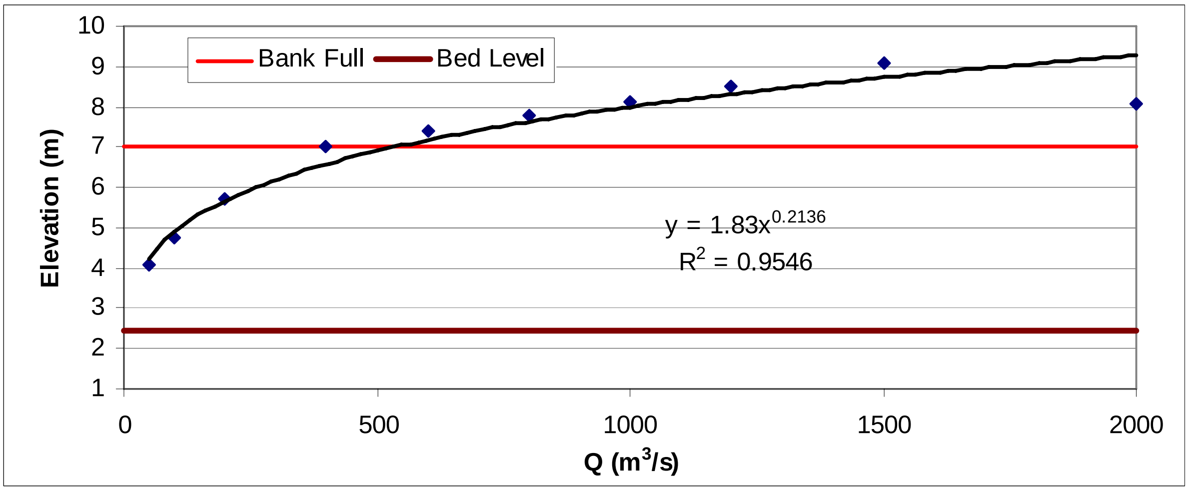


Figure 27: X-section of the Juba River at a representative location near Jammame Stretch



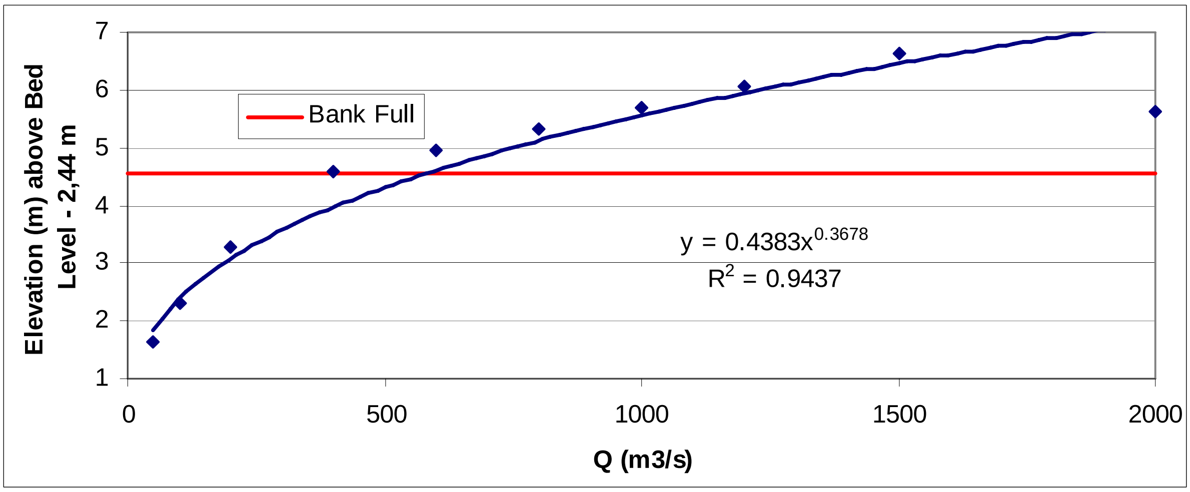


Figure 28: Theoretical Rating Curve of the Juba River at a representative location near Jammame Stretch[11]

3.6.2 Shabelle River

Three stretches of the Shabelle River were analysed, near Belet Weyne, Upper Jowhar and Afgoi and, steady flow conditions for 6 different flows were considered (Table 13). Manning's roughness' coefficient (n) values of 0.02 and 0.025 were assumed for the channel and bank respectively, and sub-critical flow boundary conditions were assumed in the most downstream station.

[11] Note: The rating curve is not valid after bank full condition is reached as the modelling did not include the flood plain modelling.

Table 13 : Flow Conditions (Profile) Analysed for the Shabelle River

Profile	PF1	PF2	PF3	PF4	PF5	PF6
Flow (m^3/s)	50	100	200	300	400	500

The results of the different river stretches are presented below.

River Stretch near Belet Weyne

The schematic plot, cross section and theoretical rating curve of a representative station location are presented in Figure 29, Figure 30 and Figure 31.

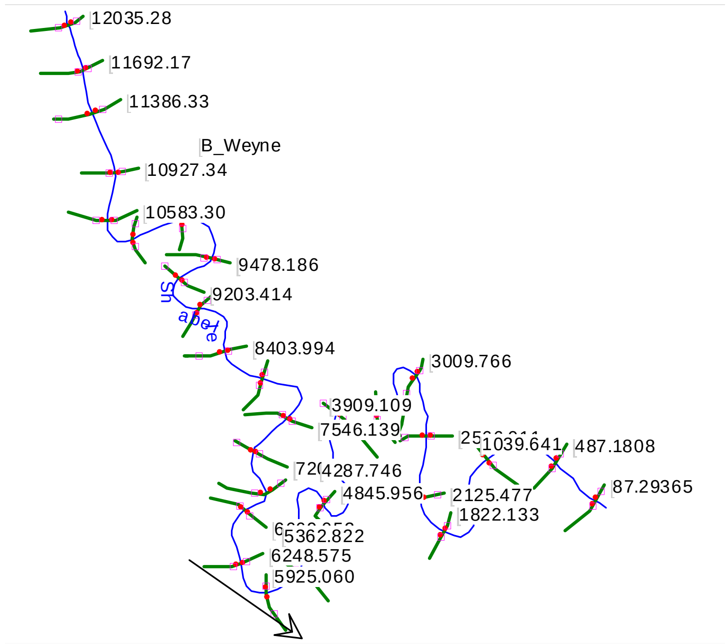


Figure 29: Schematic Plot of the Shabelle River near Belet Weyne Stretch

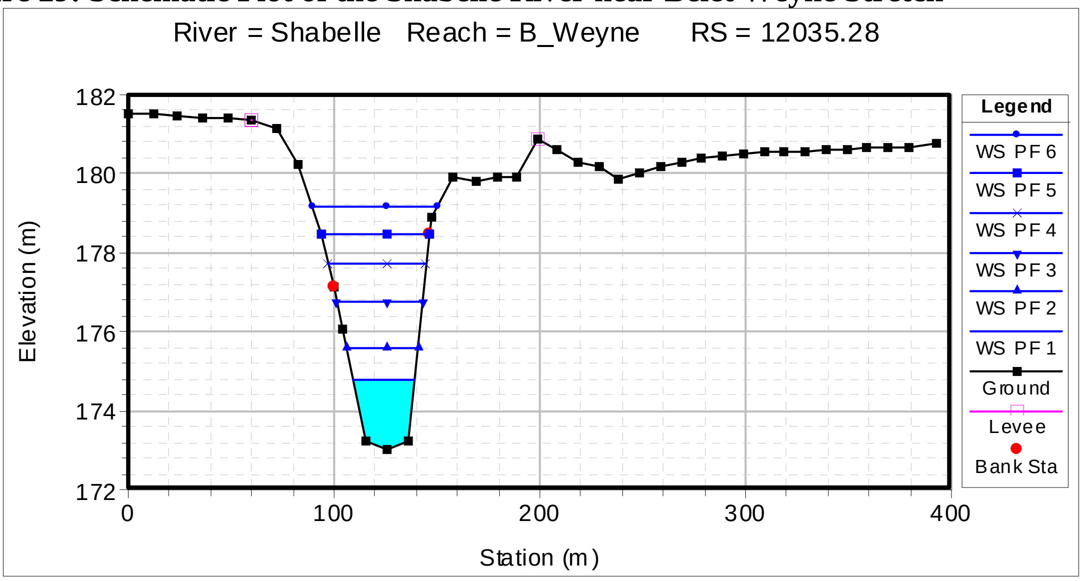
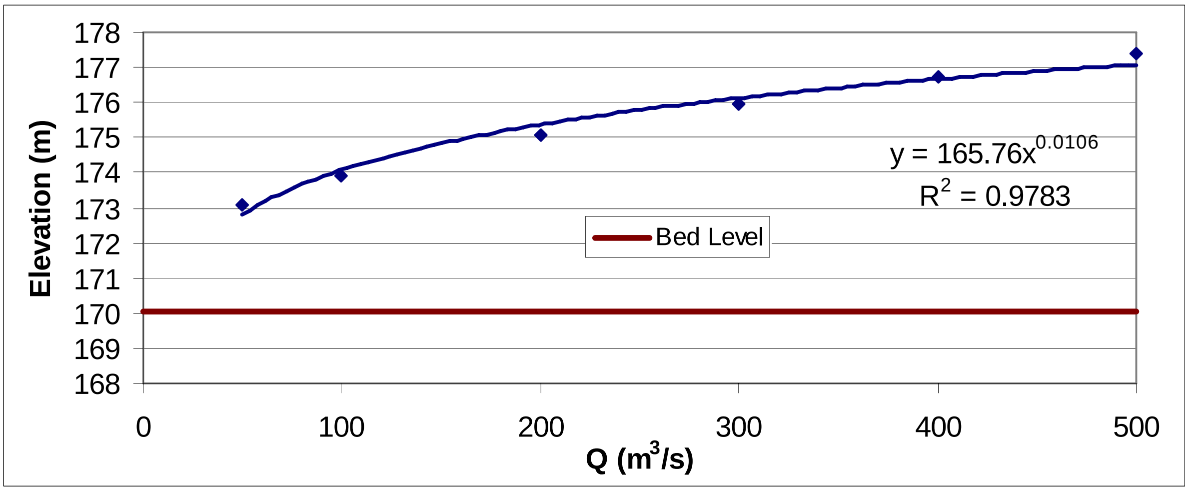


Figure 30: X-section of the Shabelle River at a representative location near Belet Weyne Stretch



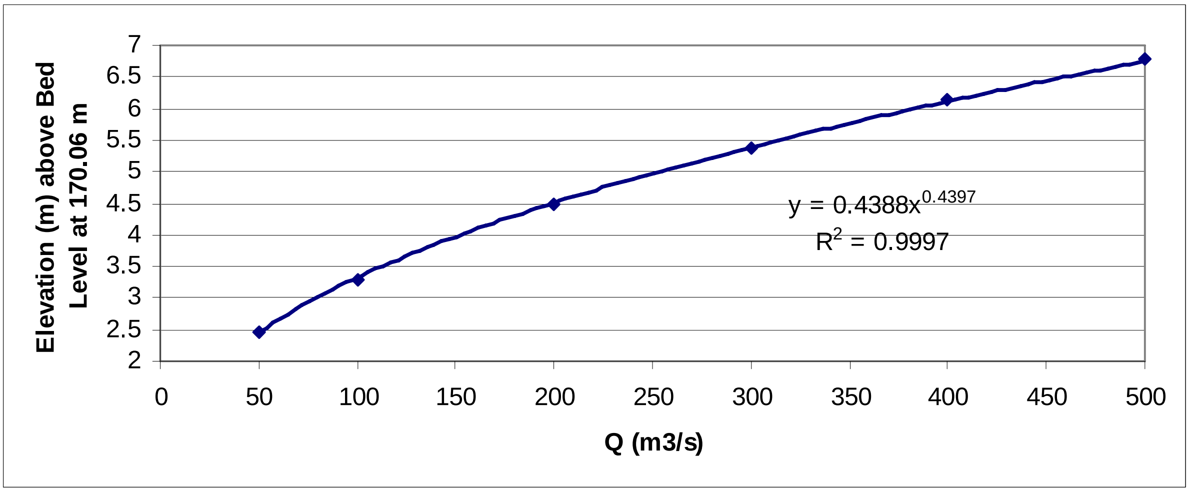


Figure 31: Theoretical Rating Curve of the Shabelle River at a representative location near Belet Weyne Stretch

River Stretch in Upper Jowhar Area

The schematic plot, cross section and theoretical rating curve of a representative station location are presented in
Figure 32,
Figure **33**,
Figure **34** and Figure 35. It should be noted that the bank full condition in Upper Jowhar stretch is a reached in less than 100 m^3/s.

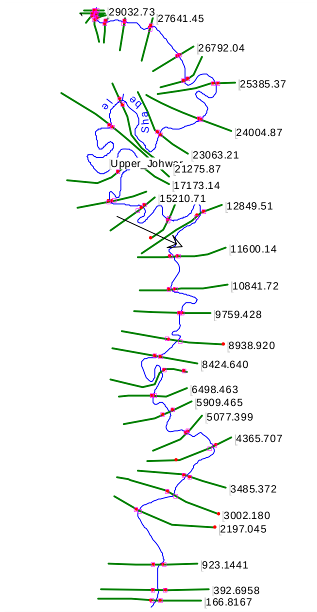


Figure 32: Schematic Plot of the Shabelle River in Upper Jowhar Stretch (downstream of Chinese Canal)

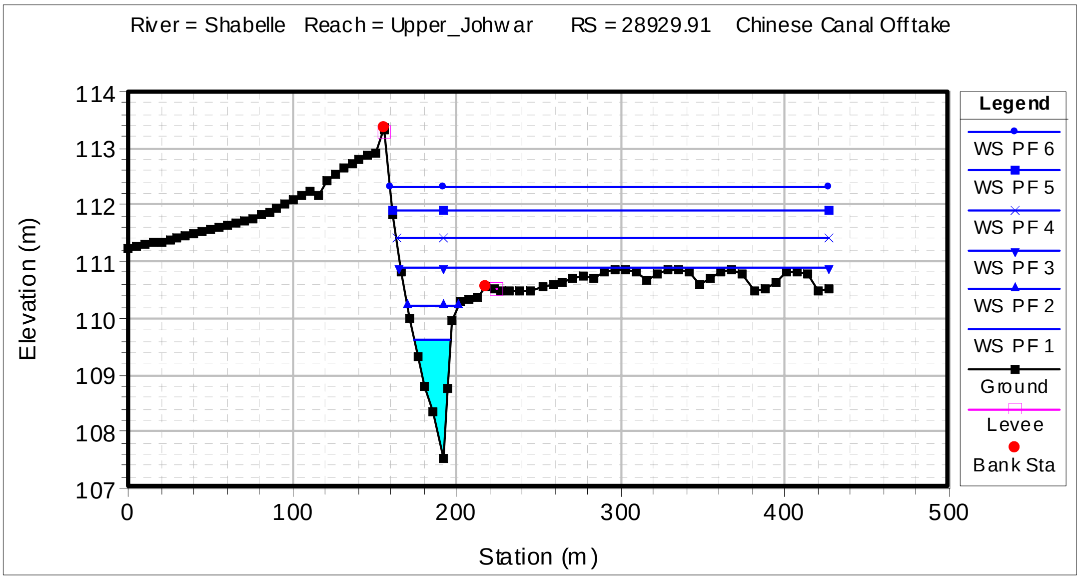


Figure 33: X-section of the Shabelle River at the Chinese Canal in Upper Johwar Stretch

Note:

1. The above cross section is at the lateral weir section leading to the Chinese Canal. It can be seen that the flood relief canal starts drawing water when the discharge is above 100-m^3/s as illustrated in profile PF3.
2. This also mean that the water in the downstream stretch is reduces after the flood relief canal starts drawing water
3. Currently, the canal is not in operation though.

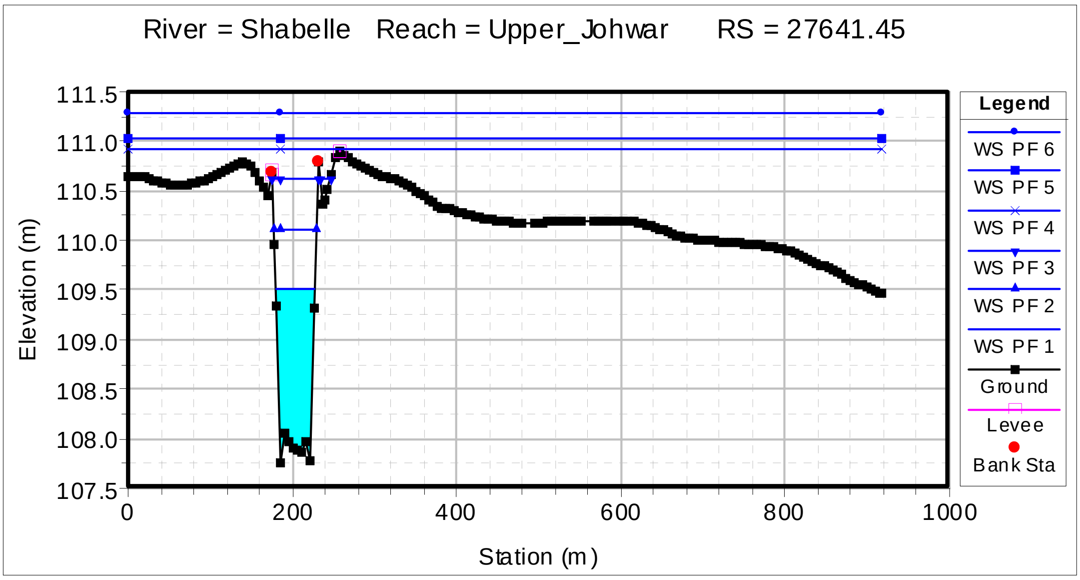
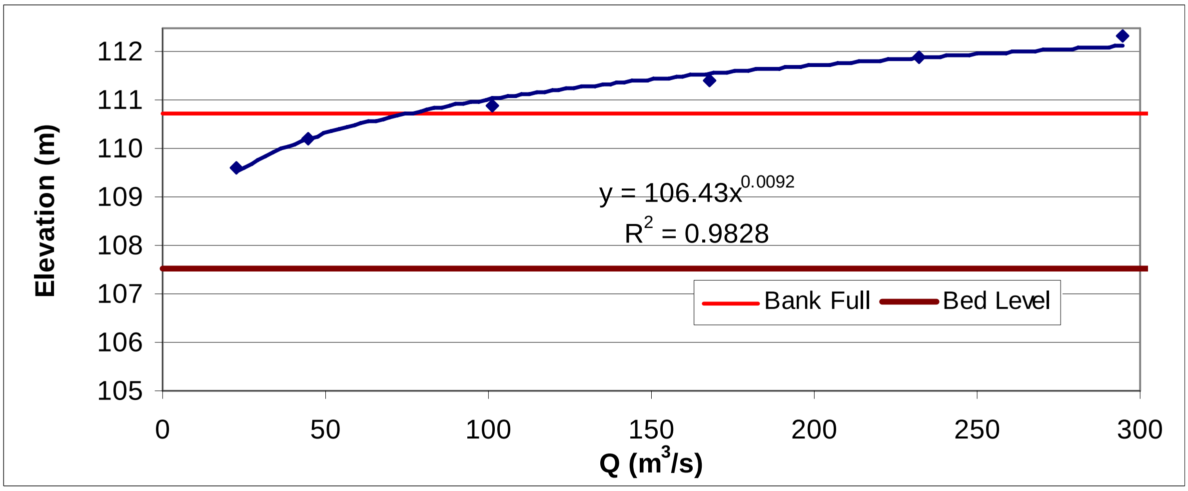


Figure 34: X-section of the Shabelle River at a representative location in Upper Jowhar Stretch



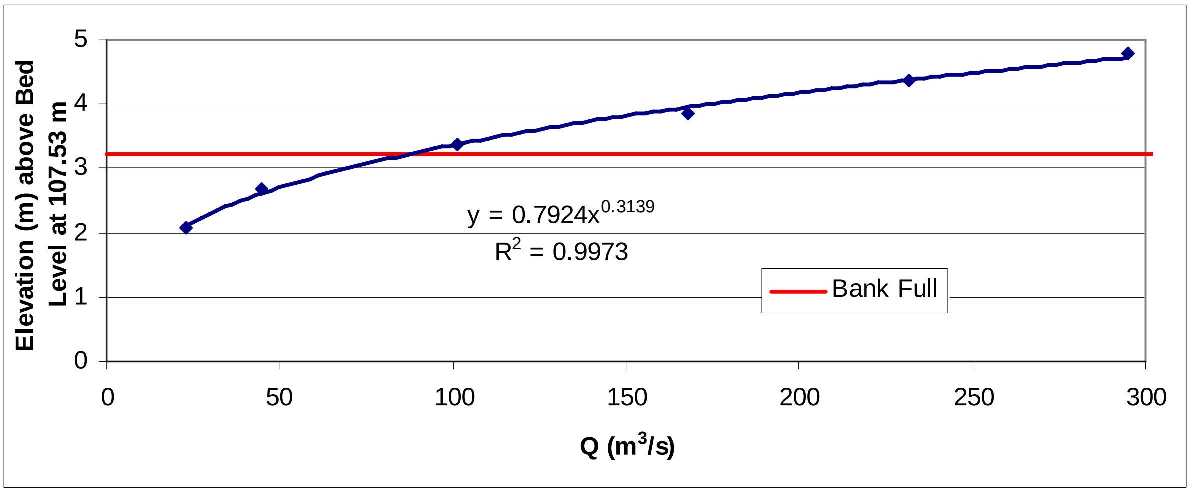


Figure 35: Theoretical Rating Curve of the Shabelle River at a representative location near Upper Jowhar Stretch

Note: The rating curve is not valid after bank full condition (less than 100 m^3/s or elev. 110.75 m) is reached as the modelling did not include the flood plain modelling.

River Stretch near Afgoi

The schematic plot, cross section and theoretical rating curve of a representative station location are presented in
Figure 36,
Figure 37 and Figure 38. It should be noted that the bank full condition near Afgoi is reached with discharge a little more than 120 m3/s.

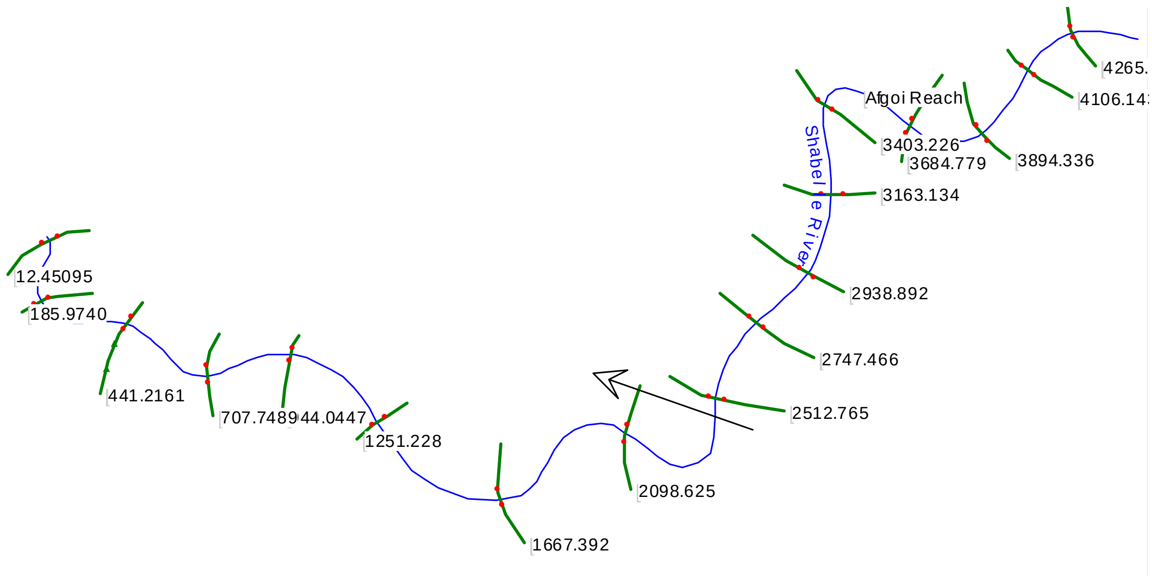


Figure 36: Schematic Plot of the Shabelle River in Afgoi Stretch

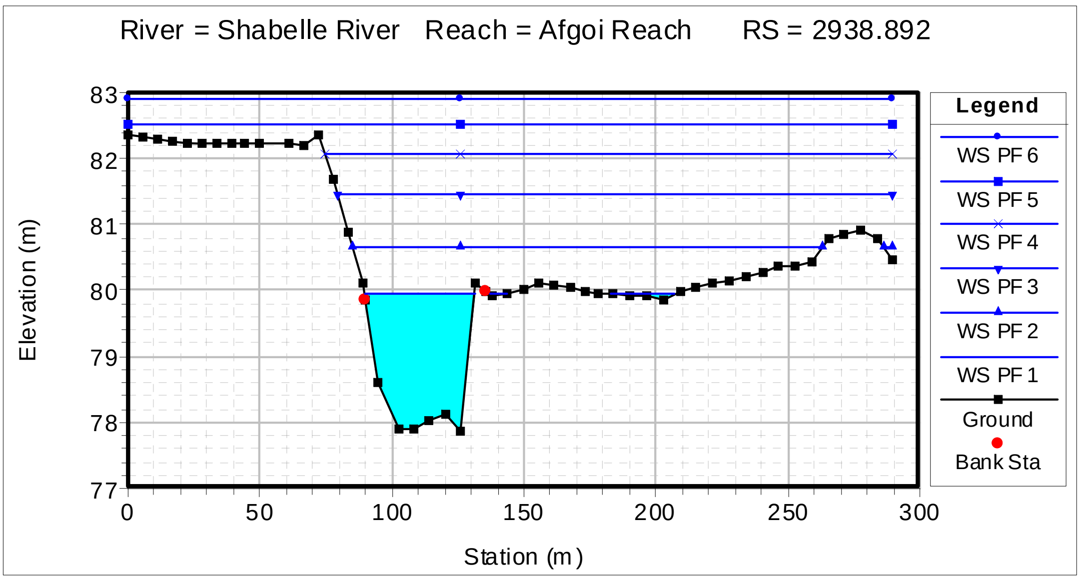


Figure 37: X-section of the Shabelle River at a representative location in Afgoi Stretch

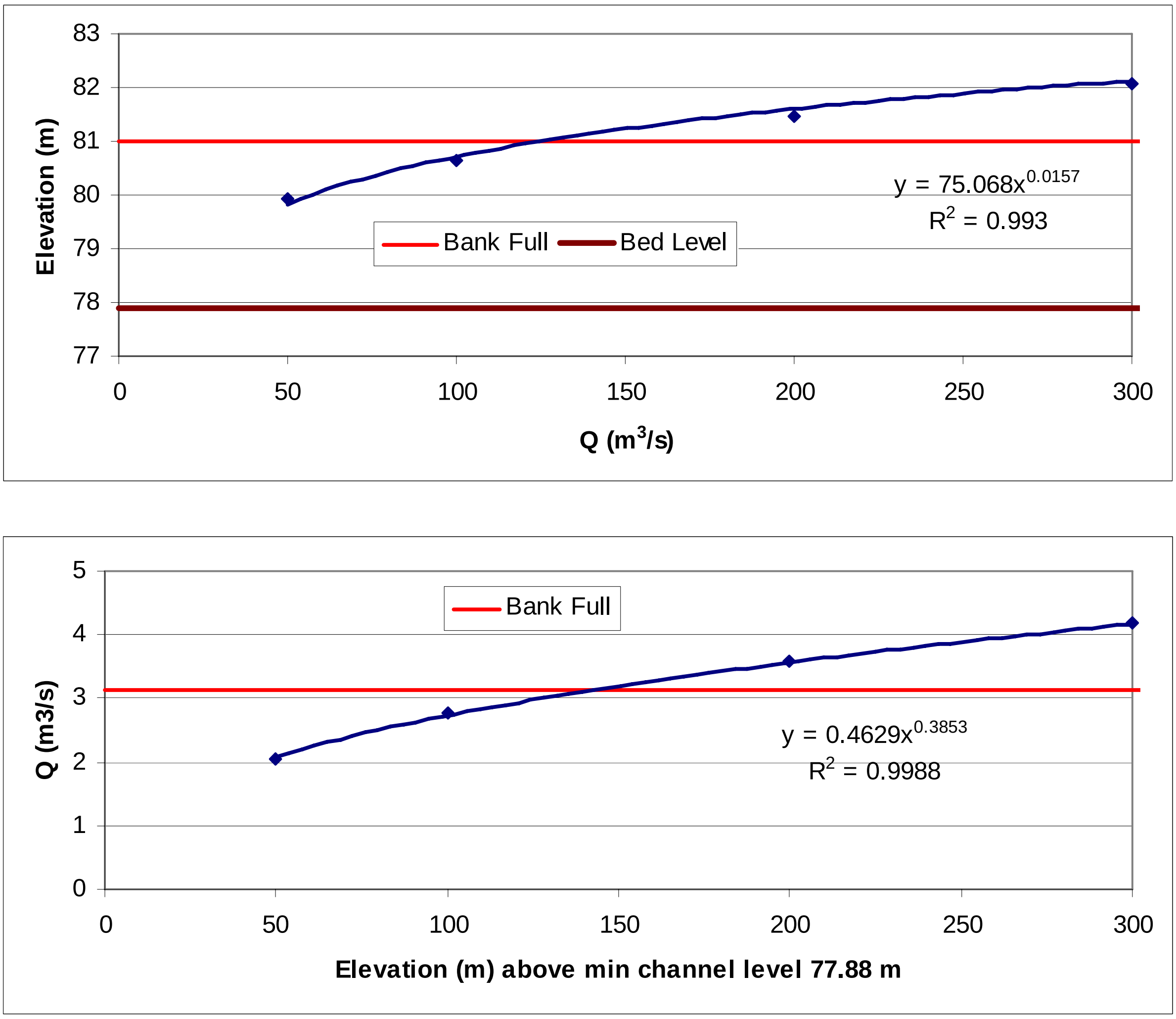


Figure 38: Theoretical Rating Curve of the Shabelle River at a representative location near Afgoi

Note:
1. The bank level is at about elevation 81 m (3.18 m about bed level of 77.88).
2. The bank full condition is reached when the flow is a little more that 120 m^3/s at this location in Afgoi area.
3. The rating curve is not valid after bank full condition is reached as the modelling did not include the flood plain modelling.
4. It should also be noted that the bank full condition may already have reached in the upper stretches of the river and hence bank full condition may not reach at this location.

3.7 Flood Inundation Mapping Studies

The results from HEC RAS analysis were further post-processed using HEC GEORAS to prepare flood inundation maps for different flow conditions. Figure 39 and Figure 40 present flood inundation maps for Jammame stretch in Juba River and Upper Jowhar stretch in Shabelle River. The inundation depths are preliminary since the full flood plains were not included in the river analysis modelling exercise.

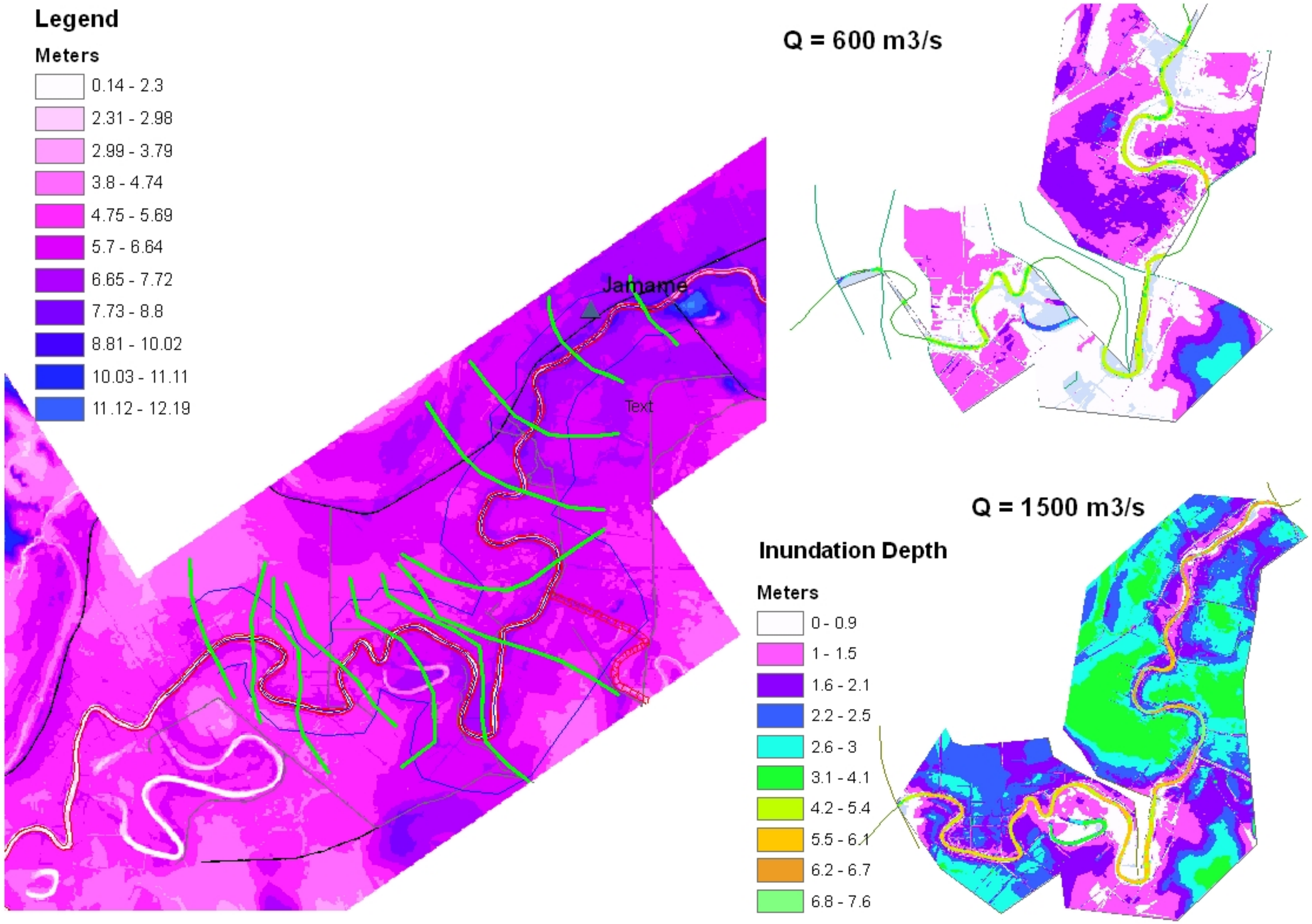


Figure 39 : Flood Inundation Map for Juba River near Jammame Reach

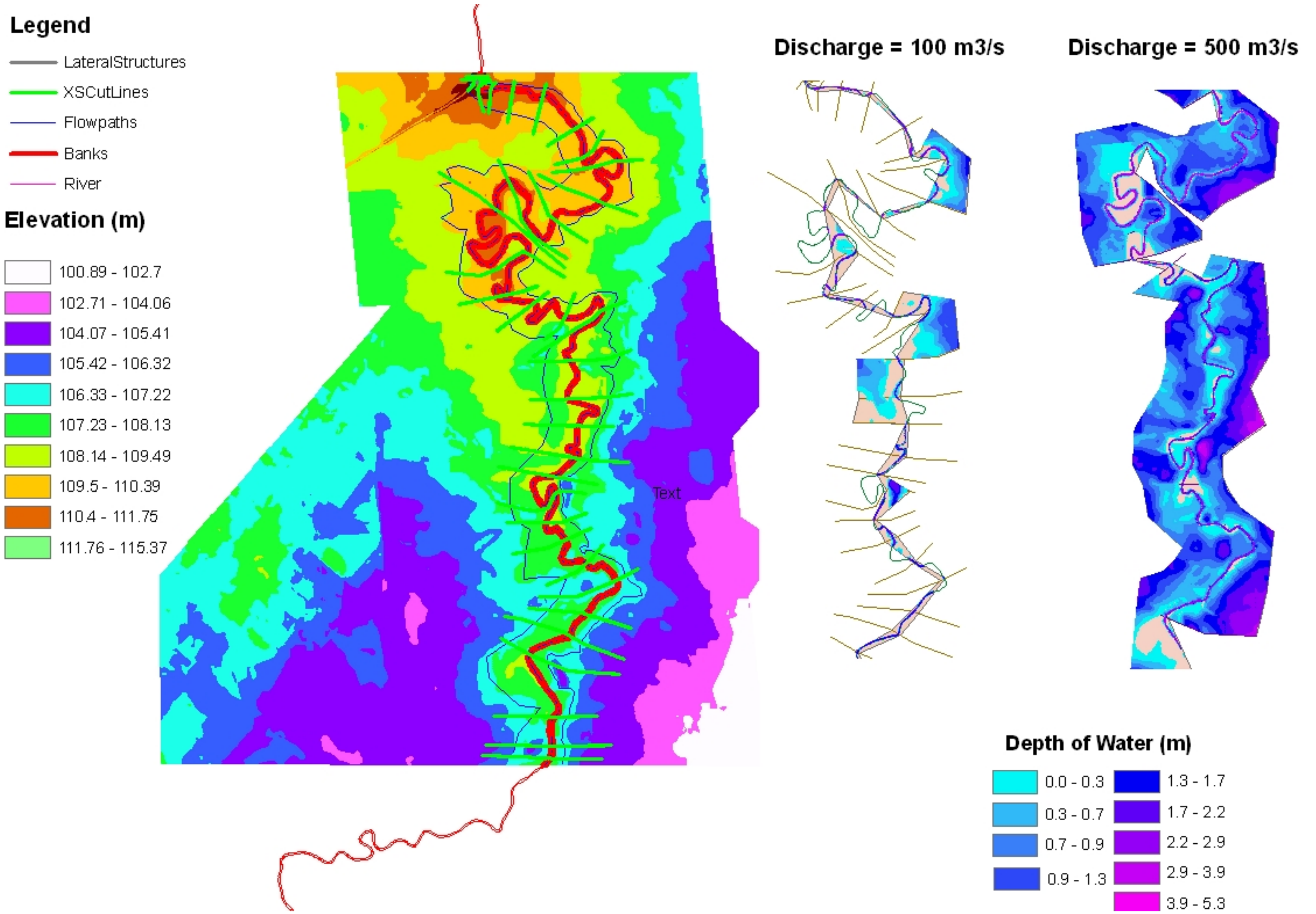


Figure 40: Flood Inundation Map for Shabelle River at upper Jowhar Reach D/S of the Chinese Canal)

4. Irrigated Agriculture

4.1 Pre-war Irrigation Infrastructure

Somalia has a long history of irrigated agriculture on the alluvial plains of the Juba and Shabelle Rivers. There were altogether ten barrages operational in the two rivers (one in Juba and nine in Shabelle) which fed many canal off-takes. Large commercial schemes of irrigated sugarcane, rice, banana, citrus and other fruit crops used to operate in the Shabelle below Jowhar and in the Juba near Jilib. Since the early 1990s much of the irrigation infrastructure has deteriorated. Opportunities exist to revive old schemes or to grow the same crops in smaller schemes. Annex B presents the barrages and irrigation schemes that were operational before 1990.

According to pre-war statistics, crop production accounted for just over 20% of the foreign exchange. 150,000ha of land were spate irrigated and around 50,000ha under full control irrigation schemes in the Juba-Shabelle basin. Civil war aided with El Nino floods in 1997/98 have led to the total collapse of all large irrigation schemes and agricultural exports are now almost zero. However, even in the present context, 70% of the country's cereal production is from Juba-Shabelle basin 60% of the country's maize is produced in the Lower Shabelle region primarily by small holders' farmers.

The major crops grown where irrigation is available are fruit trees, tomatoes, maize, sesame, groundnuts, rice, cowpea and other vegetables.

4.2 Irrigation Areas and Cropping Pattern

Data on irrigated areas in the two rivers are scarce and not reliable. Although there is a large area of land suitable for agriculture in the riverine areas of the two rivers, the availability of water is a constraint for irrigation. A study by Henry (1979) estimated an irrigated area of 38,685ha in 1979 and a potential of 65,000ha in Shabelle flood plains. Similarly, committed irrigated area was estimated as 73,210ha and total potential was estimated as 221,500ha in the Juba riverine areas, see Annex B.

There were several types of cropping patterns practiced when the irrigation infrastructure was in operation. The cropping patterns for the irrigated agriculture in the Juba and Shabelle River Basins consist of fruit trees, maize and groundnuts in *Gu* and *Deyr* periods and tomatoes, sesame, cow pea and vegetables in *Deyr* and *Jilaal* seasons. These cropping patterns are now not valid as the irrigation infrastructure (barrages and canals) are all in-operational. However, in order to estimate the irrigation potential two cropping patterns were considered to estimate the irrigation water requirement. The first is the general cropping pattern (CP-1) adapted from Henry (1979), as given in Table 14. The other is the one that has been adapted from previous SWALIM studies as given in Table 15.

Table 14: Representative Cropping Pattern and % Areas (CP-1)[12]

Crop	% of Total Area				
	Gu		Deyr		Perennial
	% Area	Start	% Area	Start	% Area
Maize	60	Mid April	27	Mid September	
Groundnuts	2	Beginning of. April			
Sesame			40	Mid September	
Vegetable	5	Mid April			
Bananas					10
Citrus					7
Sugarcane					16

Table 15: Crop Calendar for Irrigated Agriculture (CP-2)[13]

Crop	% Area	Start	End	
Citrus	10			Perennial
Tomato	10	1 August	24 December	
Maize	80	1 April	14 August	
Maize	25	15 August	18 December	
Groundnuts	10	1 February	21 June	
Groundnuts	10	1 August	19 December	
Sesame	35	15 August	4 November	
Vegetable	10	15 August	4 November	
Vegetable	10	12 August	4 November	
Groundnut	10	20 November	8 February	

4.3 Irrigation Water Requirement and Water Balance

Average crop water requirements were calculated for the cropping patterns described earlier for climatic conditions in Jowhar and Afgoi climatic stations in the Shabelle River and Jilib climatic station in the Juba River, respectively, (see
Table 16,
Table 17 and

Table 18). An overall irrigation efficiency of 45% was considered to calculate the irrigation water withdrawal (Field Application Efficiency – 60% and Distribution Efficiency – 75%).

As the major irrigated areas and infrastructure lie in the lower portions of both the rivers, overall water balances of available surface water and irrigation water requirements for two scenarios of irrigation are presented in
Table 19,

[12] Adapted from Henry (1979)

[13] Adapted from SWALIM (2006)

Table 20, **Table 21** and **Table 22**.

Irrigation water requirements were compared to average, 50% and 80% exceedance probabilities flow. The months with flows less than the irrigation water demand for the first scenario is highlighted in **bold red** while the months with flows less than the water demand for the second scenario of irrigation water use were highlighted in ***blue italics***.

Table 16 : Climate and Potential Evapotranspiration Data for Jowhar

Climate and ET_0 (grass) Data

Station **Jowhar**
Altitude: 100m AMSL
Latitude: 2.76 Deg. (North) Longitude: 45.50 Deg. (East)

Month	Max Temp (^{0}C)	Mini Temp (^{0}C)	Humidity (%)	Wind Speed (Km/day)	Sun Shine (Hours)	Solar Radiation (MJ/m^2/d)	ET_0 (mm/day)
January	34	21.1	75	172.8	7.8	20.3	5.01
February	35.2	21.5	72	172.8	8.7	22.6	5.65
March	36.2	22.5	72	155.5	8.2	22.3	5.68
April	35.7	23.2	75	103.7	6.4	19.2	4.69
May	33.5	23	80	103.7	6.2	18	4.16
June	31.5	21.6	83	129.6	5.3	16.1	3.68
July	30.1	20.7	82	138.2	5.3	16.3	3.64
August	31	20.7	80	129.6	6.3	18.5	4.12
September	32.2	21.2	79	129.6	7.3	20.7	4.62
October	32.7	22	81	172.8	6.3	18.9	4.51
November	32.5	21.7	84	172.8	7.1	19.4	4.41
December	32.5	21.5	79	216	7.3	19.2	4.68
Average	**33.1**	**21.7**	**78.5**	**149.8**	**6.8**	**19.3**	**4.57**

Table 17 : Climate and Potential Evapotranspiration Data for Afgoi

Climate and ET_0 (grass) Data

Station : **Afgoi**
Altitude: 80 meter AMSL
Latitude: 2.13 Deg. (North) Longitude:45.13 Deg. (East)

Month	Max Temp (^{0}C)	Min Temp (^{0}C)	Humidity (%)	Wind Speed (Km/day)	Sun Shine (Hours)	Solar Radiation (MJ/m^2/d)	ET_0 (mm/day)
January	33.5	21.6	77	345.6	7.9	20.6	5.65
February	34	21.7	83	354.2	9.3	23.6	5.84
March	35	23	81	319.7	8.9	23.5	6.03
April	34.2	23.5	83	216	7.5	20.8	5.06
May	32.7	23.1	87	216	6.5	18.4	4.25

June	31.2	22.6	89	259.2	6.2	17.3	3.85
July	30.5	21.5	84	259.2	7.9	19.9	4.4
August	31.1	21.5	85	259.2	8.2	21.3	4.68
September	32	21.7	82	259.2	8.5	22.5	5.16
October	32.2	22	82	233.3	7.6	21	4.89
November	32.2	21.7	78	172.8	6.7	18.9	4.5
December	33	21.6	77	276.5	6.6	18.3	4.97
Average	**32.6**	**22.1**	**82.3**	**264.2**	**7.7**	**20.5**	**4.94**

Table 18 : Climate and Potential Evapotranspiration Data for Jilib

Climate and ET_0 (grass) Data

Station **Jilib**
Altitude: 0 m AMSL
Latitude: 0.43 Deg. (North) Longitude: 42.80 Deg. (East)

Month	Max Temp (^{0}C)	Min Temp (^{0}C)	Humidity (%)	Wind Speed (Km/day)	Sun Shine (Hours)	Solar Radiation (MJ/m^2/day)	ET_0 (mm/day)
January	35	22.1	75	146.9	8.2	21.3	5.18
February	35.5	21.7	76	172.8	8.1	21.9	5.5
March	36	22.2	76	155.5	9	23.7	5.77
April	35.5	23	80	69.1	6.8	19.6	4.47
May	33.2	23	84	51.8	6.8	18.6	3.95
June	32	21.2	87	51.8	6.2	17.1	3.52
July	30.5	20.5	85	51.8	6.3	17.4	3.49
August	31.2	20.2	83	51.8	7	19.4	3.91
September	32.2	20.2	82	86.4	7.5	20.9	4.42
October	33	21.5	80	95	6.7	19.7	4.39
November	33.7	22	84	69.1	6	18.1	3.99
December	34.5	21.7	81	95	7.4	19.8	4.46
Average	**33.5**	**21.6**	**81.1**	**91.4**	**7.2**	**19.8**	**4.42**

Table 19 : Irrigation Water Demand and Water Availability in Shabelle River for CP-1

	Afgoi	Irrigated Area		Flows at Mahadey Weyne		
	Irrigation Requirement	Scenario-1 38,695 ha	Scenario-2 65,017 ha	80%	50%	Average
Month	**L/s/ha**	**MCM**	**MCM**	**MCM**	**MCM**	**MCM**
Jan	0.59	61.1	102.7	**17.7**	**34.6**	**46.1**
Feb	0.36	33.7	56.6	**9.7**	**22.3**	**31.7**
Mar	0.43	44.6	74.9	**6.4**	**23.6**	***56.4***
Apr	0.15	15.0	25.3	**12.7**	96.4	138.9
May	0.18	18.7	31.3	146.8	305.9	279.9
Jun	0.72	72.2	121.3	***77.2***	163.3	193.8
Jul	0.83	86.0	144.5	**64.5**	***126.4***	***139.4***
Aug	0.74	76.7	128.9	181.3	279.1	263.2
Sep	0.47	47.1	79.2	263.1	348.6	318.3

Oct	0.42	43.5	73.1	211.3	310.7	298.2
Nov	0.49	49.1	82.6	***78.3***	163.3	193.5
Dec	0.70	72.5	121.9	**32.4**	**59.5**	***100.5***
Total		**620.4**	**1042.4**	**1101.5**	**1933.6**	**2059.8**

Table 20 : Irrigation Water Demand and Water Availability in Shabelle River for CP-2

	Afgoi	Irrigated Area		Flows at Mahadey Weyne		
	Irrigation Requirement	Scenario-1 38,695 ha	Scenario-2 65,017 ha	80%	50%	Average
Month	**L/s/ha**	**MCM**	**MCM**	**MCM**	**MCM**	**MCM**
Jan	0.25	25.9	43.5	**17.7**	***34.6***	46.1
Feb	0.2	18.7	31.5	**9.7**	***22.3***	31.7
Mar	0.36	37.3	62.7	**6.4**	**23.6**	***56.4***
Apr	0.13	13.0	21.9	**12.7**	96.4	138.9
May	0.61	63.2	106.2	146.8	305.9	279.9
Jun	0.74	74.2	124.7	77.2	163.3	193.8
Jul	0.38	39.4	66.2	***64.5***	126.4	139.4
Aug	0.2	20.7	34.8	181.3	279.1	263.2
Sep	0.69	69.2	116.3	263.1	348.6	318.3
Oct	0.83	86.0	144.5	211.3	310.7	298.2
Nov	0.38	38.1	64.0	78.3	163.3	193.5
Dec	0.45	46.6	78.4	**32.4**	***59.5***	100.5
Total		**532.5**	**894.8**	**1101.5**	**1933.6**	**2059.8**

Table 21 : Irrigation Water Demand and Water Availability in Juba River for CP-1

	Jilib	Irrigated Area (ha)		Flow at Bardheere		
	Irrigation Requirement	Scenario-1 73,210ha	Scenario-2 221,500ha	80%	50%	Average
Month	**L/s/ha**	**MCM**	**MCM**	**MCM**	**MCM**	**MCM**
Jan	0.54	105.9	320.4	**62.4**	**97.5**	***125.9***
Feb	0.34	60.2	182.2	**35.3**	**50.6**	***72.6***
Mar	0.41	80.4	243.2	**25.4**	**43.9**	***96.4***
Apr	0.00	0.0	0.0	54.4	217.5	385.2
May	0.00	0.0	0.0	300.8	591.4	788.0
Jun	0.31	58.8	178.0	263.6	447.4	550.5
Jul	0.64	125.5	379.7	336.7	470.1	504.3
Aug	0.59	115.7	350.0	427.7	599.4	640.9
Sep	0.28	53.1	160.8	454.1	672.9	701.1
Oct	0.39	76.5	231.4	563.5	894.6	1066.3
Nov	0.69	130.9	396.1	405.4	686.1	855.4
Dec	0.65	127.5	385.6	143.8	238.6	330.8
Total		**934.5**	**2827.4**	**3073.3**	**5009.9**	**6117.4**

Table 22 : Irrigation Water Demand and Water Availability in Shabelle River for CP-2

Month	Jilib Irrigation Requirement L/s/ha	Irrigated Area (ha) Scenario-1 73,210ha MCM	Scenario-2 221,500ha MCM	Flow at Bardheere 80% MCM	50% MCM	Average MCM
Jan	0.25	49.0	148.3	***62.4***	***97.5***	***125.9***
Feb	0.2	35.4	107.2	**35.3**	***50.6***	***72.6***
Mar	0.36	70.6	213.6	**25.4**	**43.9**	***96.4***
Apr	0.13	24.7	74.6	54.4	217.5	385.2
May	0.61	119.6	361.9	300.8	591.4	788.0
Jun	0.74	140.4	424.9	263.6	447.4	550.5
Jul	0.38	74.5	225.4	336.7	470.1	504.3
Aug	0.2	39.2	118.7	427.7	599.4	640.9
Sep	0.69	130.9	396.1	454.1	672.9	701.1
Oct	0.83	162.8	492.4	563.5	894.6	1066.3
Nov	0.38	72.1	218.2	405.4	686.1	855.4
Dec	0.45	88.2	267.0	143.8	238.6	330.8
Total		**1007.5**	**3048.2**	**3073.3**	**5009.9**	**6117.4**

5. Summary and Conclusions

This study updated available data and past studied covering three key components:

(i) Catchment characteristics of the Juba and Shabelle River Basins
(ii) Hydrological and hydraulic regime of the two rivers
(iii) Irrigation water requirements and water balance

The catchment characteristics of the Juba and Shabelle river basins were updated at the sub-basin level using 90 m SRTM DEM and deriver products available from the 30 m DRTM DEM.

The availability of 25 cm and 50 cm vertical accuracy digital photography data (DTMs, orthophotos) of the riverine areas of the two rivers has provided valuable data to study and update the hydrological and hydraulic regime of the two rivers. This study has prepared the following using these data.

- Geo-morphological characteristics of the rivers
- River analysis at key locations using HEC RAS and HEC GEORAS

Theoretical rating curves and assessment of bank full conditions have developed at key locations. The rating curves for conditions of more than bank-full elevations are not valid and flood plain modelling was not fully carried out.

The irrigation water requirements for representative cropping patterns in the lower reaches of the Juba and Shabelle Rivers have been estimated using FAO CROPWAT software. Water balance using the flow available at Bardheere in Juba River and Mahadey Weyne in Shabelle River for different areas irrigation has been estimated.

Based on this updated study of the three components mentioned above, the following recommendations are made.

(i) The results and outputs of this study should be used to prepare the proposed River Atlas.
(ii) The catchment analysis carried out in this study should be combined with the climate and land studies carried out by SWALIM to prepare a complete Catchment Analysis Report.
(iii) This study initiated the mapping of all hydraulic infrastructures in the two rivers using the aerial photography data. This should be continued so that the river and flood analysis of the full stretch of the rivers can be carried out.
(iv) The aerial photography data should be used to study the status of all canals and irrigated areas so that a full water balance study can be carried out.
(v) The data on hydraulic structures should be updated using the aerial photography data and the field data. This is important for the hydraulic study of the rivers.
(vi) This study initiated the pre-processing of the input data from the aerial photography data for use in river hydraulic analysis using software like HEC RAS. This should be done for the full stretch of the rivers.
(vii) The 1-Dimensional River Hydraulic models (HEC RAS) used in this study is appropriate only for the channel hydraulic modelling and not for flood plain modelling. Hence a combined 1D-2D hydraulic modelling should be carried out for the river and flood plain modelling.

ANNEXES

Annex A: Hydrology

Annex A.1: Long-term Average Flows in Juba River

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Luuq (168,728 km^2)	Mean:	41.6	24.2	31.4	150.4	275.1	198.3	189.5	242.6	270.7	391.6	302.1	110.9	186.4
	Std. Dv.	30.3	22.0	45.5	158.6	154.3	112.1	62.8	78.7	89.1	161.0	202.0	72.1	57.8
	C.V.	73%	91%	145%	105%	56%	57%	33%	32%	33%	41%	67%	65%	31%
Bardheere (200,349 km^2)	Mean:	47.3	30.0	36.0	148.6	294.2	212.4	188.3	239.3	270.5	394.2	330.0	123.5	195.2
	Std. Dv.	29.5	20.8	46.1	158.0	180.0	132.2	63.5	77.1	88.6	161.4	200.9	77.9	59.4
	C.V.	62%	69%	128%	106%	61%	62%	34%	32%	33%	41%	61%	63%	30%
Marere (214,729 km^2)	Mean:	45.3	25.9	30.4	137.3	290.2	253.0	188.7	212.3	236.4	339.9	325.7	146.3	186.0
	Std. Dv.	32.0	23.0	40.5	139.9	175.4	159.0	72.2	81.9	91.6	121.9	165.6	124.4	64.0
	C.V.	71%	89%	133%	102%	60%	63%	38%	39%	39%	36%	51%	85%	34%
Kaitoi (215,604 km^2)	Mean:	54.3	31.6	28.4	117.3	254.9	227.1	183.8	224.9	248.0	319.8	313.5	146.5	178.1
	Std. Dv.	37.3	28.1	39.2	112.9	146.2	115.8	65.5	65.4	73.8	105.8	141.7	103.8	53.5
	C.V.	69%	89%	138%	96%	57%	51%	36%	29%	30%	33%	45%	71%	30%
Jamama (218,114 km^2)	Mean:	50.5	23.4	21.7	96.7	233.2	205.2	167.4	211.3	247.1	308.8	311.0	142.8	169.5
	Std. Dv.	38.5	18.7	31.0	103.5	128.8	115.5	65.9	72.7	82.5	96.4	114.9	99.2	48.5
	C.V.	76%	80%	143%	107%	55%	56%	39%	34%	33%	31%	37%	70%	29%

Annex A.2: Long-term Average Flows in Shabelle River

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Belet Weyne (193,224 km^2)	**Mean:**	13.5	13.8	30.0	79.8	151.2	82.7	57.0	110.0	151.8	129.6	77.5	36.9	75.0
	Std. Dv.	11.1	13.3	35.0	68.2	88.2	65.6	22.5	32.3	57.3	60.2	62.9	39.8	22.6
	C.V.	82%	96%	117%	85%	58%	79%	40%	29%	38%	46%	81%	108%	30%
Bulu Burti (207,488 km^2)	**Mean:**	14.3	9.8	14.5	31.9	65.6	56.1	40.8	67.3	74.8	71.9	57.2	31.7	44.7
	Std. Dv.	15.0	12.8	18.1	24.7	19.7	22.4	19.7	19.3	10.3	9.5	20.1	25.5	10.7
	C.V.	105%	130%	125%	78%	30%	40%	48%	29%	14%	13%	35%	81%	24%
M. Weyne (209,865 km^2)	**Mean:**	17.2	13.1	21.1	53.6	104.5	74.8	52.0	98.3	122.8	111.4	74.6	37.5	65.1
	Std. Dv.	12.9	12.0	25.4	38.1	39.0	40.7	25.5	27.9	26.9	27.8	37.4	33.7	15.3
	C.V.	75%	92%	121%	71%	37%	54%	49%	28%	22%	25%	50%	90%	23%
Balcad (214,516 km^2)	**Mean:**	17.2	13.1	21.1	53.6	104.5	74.8	52.0	98.3	122.8	111.4	74.6	37.5	65.1
	Std. Dv.	12.9	12.0	25.4	38.1	39.0	40.7	25.5	27.9	26.9	27.8	37.4	33.7	15.3
	C.V.	75%	92%	121%	71%	37%	54%	49%	28%	22%	25%	50%	90%	23%
Afgoi (244,672 km^2)	**Mean:**	14.2	9.6	14.7	34.7	70.9	57.4	40.0	72.8	84.8	79.2	60.4	32.4	47.6
	Std. Dv.	13.9	11.7	19.6	27.1	22.9	25.8	20.0	22.3	15.7	14.6	24.6	27.1	12.1
	C.V.	98%	122%	133%	78%	32%	45%	50%	31%	18%	18%	41%	84%	26%
Awdhegle (245,069	**Mean:**	14.3	9.8	14.5	31.9	65.6	56.1	40.8	67.3	74.8	71.9	57.2	31.7	44.7
	Std. Dv.	15.0	12.8	18.1	24.7	19.7	22.4	19.7	19.3	10.3	9.5	20.1	25.5	10.7

km²) **C.V.**	105%	130 %	125 %	78%	30%	40%	48%	29%	14%	13%	35%	81%	24%

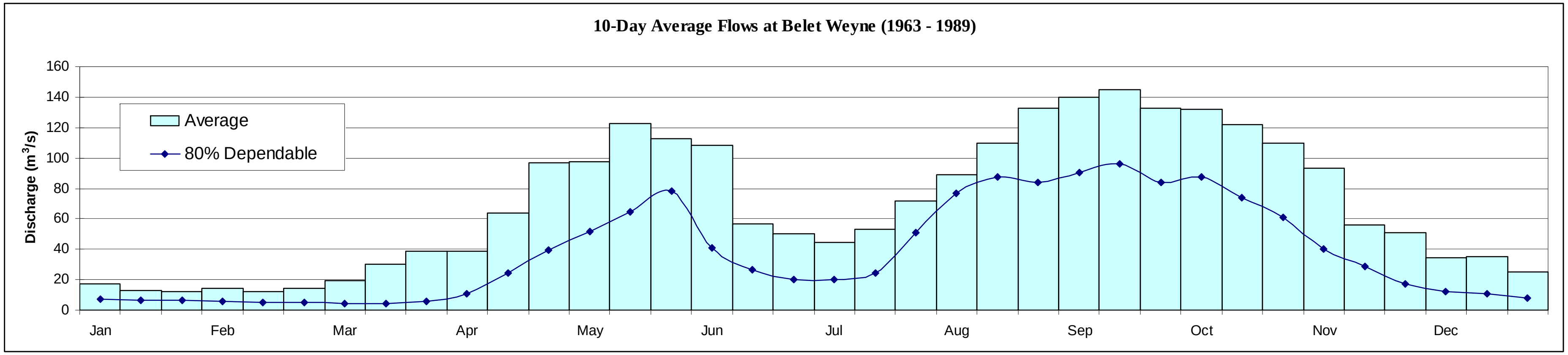
Annex A.3: Summary of Flow Duration Curve in Juba River (m3/s)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Luuq	Mean	41.3	24.2	31.4	150.4	275.1	198.3	189.5	242.6	270.7	396.8	302.1	110.9	186.1
	20%	60.6	36.2	36.4	216.7	418.7	271.7	248.9	326.6	368.7	560.0	412.6	174.0	298.2
	50%	30.0	16.0	10.3	91.1	222.3	169.9	182.8	227.9	263.7	327.9	244.2	81.6	151.9
	80%	17.3	6.4	5.5	15.3	102.1	96.0	122.0	161.1	170.8	217.4	135.1	46.0	31.0
Bardheere	Mean	47.0	30.0	36.0	148.6	294.2	212.4	188.3	239.3	270.5	398.1	330.0	123.5	193.2
	20%	66.6	44.4	36.7	216.8	436.2	297.8	245.4	319.2	365.2	555.6	447.2	192.7	305.6
	50%	36.4	20.9	16.4	83.9	220.8	172.6	175.5	223.8	259.6	334.0	264.7	89.1	155.3
	80%	23.3	14.6	9.5	21.0	112.3	101.7	125.7	159.7	175.2	210.4	156.4	53.7	35.9
Marere	Mean	45.3	25.9	30.4	137.3	290.2	253.0	188.7	212.3	236.4	339.9	325.7	146.3	186.0
	20%	65.7	47.3	38.4	220.1	533.9	403.9	266.9	292.2	348.1	508.3	540.6	245.4	318.1
	50%	33.7	16.3	11.8	70.5	224.7	216.9	178.0	200.8	222.8	334.6	296.8	86.5	147.5
	80%	20.4	7.6	3.8	10.7	122.6	101.0	111.0	137.8	135.6	185.3	148.1	51.1	32.1
Kaitoi	Mean	55.2	32.2	29.1	119.3	252.4	209.1	181.7	235.6	253.7	334.2	310.8	145.1	179.9
	20%	77.9	52.4	37.6	215.2	477.0	314.8	238.7	313.4	335.3	472.0	455.0	238.2	301.0
	50%	44.2	24.5	14.2	42.4	191.8	178.7	168.9	216.4	250.4	303.7	280.6	100.0	154.7
	80%	27.2	8.7	3.3	9.0	100.5	99.8	115.1	163.9	174.4	203.7	158.8	59.0	36.1
Jamamme	Mean	50.4	23.3	21.7	96.7	233.2	205.2	167.4	211.3	247.1	307.4	311.0	142.8	168.1
	20%	73.0	36.5	29.3	169.6	415.7	310.4	229.1	276.6	342.1	452.6	460.3	228.4	293.7
	50%	36.4	18.2	9.9	31.6	199.1	174.7	157.6	203.4	245.3	286.4	312.2	101.9	143.6
	80%	20.6	6.9	0.9	5.0	81.0	93.4	100.8	144.5	161.3	183.7	173.7	56.8	27.5

Annex A.4: Summary of Flow Duration Curves in Shabelle River (m^3/s)

	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Belet Weyne	Mean	14.3	13.8	30.3	80.5	152.8	82.8	57.0	110.7	152.0	130.2	77.7	37.2	78.3
	20%	21.3	17.9	56.8	129.6	242.4	124.7	82.5	138.3	198.1	184.9	121.9	57.3	137.1
	50%	10.5	8.6	11.3	64.2	130.4	52.6	54.6	116.4	153.2	118.7	46.7	17.9	60.8
	80%	5.8	4.7	3.8	14.6	63.8	28.0	30.9	77.7	99.1	69.1	22.6	10.0	14.4
Bulo Burti	Mean	13.3	10.5	20.8	61.3	132.8	78.8	49.9	99.5	136.4	122.9	76.1	34.3	69.7
	20%	21.2	16.0	21.8	110.1	209.1	115.9	75.5	127.2	173.5	173.3	118.4	46.9	121.6
	50%	8.8	6.4	7.2	42.0	111.5	50.7	47.6	104.2	138.5	108.7	51.0	16.0	49.7
	80%	3.9	2.0	1.1	5.5	53.9	21.8	22.8	68.7	97.1	70.6	24.1	8.3	10.0
M. Weyne	Mean	17.2	13.1	21.1	53.6	104.5	74.8	52.0	98.3	122.8	111.4	74.6	37.5	65.1
	20%	25.9	20.3	23.9	107.0	145.1	129.9	79.1	129.7	140.0	140.8	125.6	63.3	125.2
	50%	12.9	9.2	8.8	37.2	114.2	63.0	47.2	104.2	134.5	116.0	63.0	22.2	52.9
	80%	6.6	4.0	2.4	4.9	54.8	29.8	24.1	67.7	101.5	78.9	30.2	12.1	13.3
Afgoi	Mean	13.3	10.5	20.8	61.3	132.8	78.8	49.9	99.5	136.4	122.9	76.1	34.3	69.7
	20%	21.2	16.0	21.8	110.1	209.1	115.9	75.5	127.2	173.5	173.3	118.4	46.9	121.6
	50%	8.8	6.4	7.2	42.0	111.5	50.7	47.6	104.2	138.5	108.7	51.0	16.0	49.7
	80%	3.9	2.0	1.1	5.5	53.9	21.8	22.8	68.7	97.1	70.6	24.1	8.3	10.0
Awdhegle	Mean	14.3	9.8	14.5	31.9	65.6	56.1	40.8	67.3	74.8	71.9	57.2	31.7	44.7
	20%	26.4	17.1	26.9	72.8	85.2	83.0	64.5	84.6	83.3	81.9	81.4	62.1	77.7
	50%	8.1	4.1	3.0	19.8	74.0	63.5	39.1	74.0	77.4	74.0	62.7	22.0	45.7
	80%	1.7	0.0	0.0	0.0	42.7	28.4	17.9	49.2	70.0	63.8	32.7	7.3	8.7

Annex A.5 –Long-term 10-Day Flow Statistics



Year	Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec		
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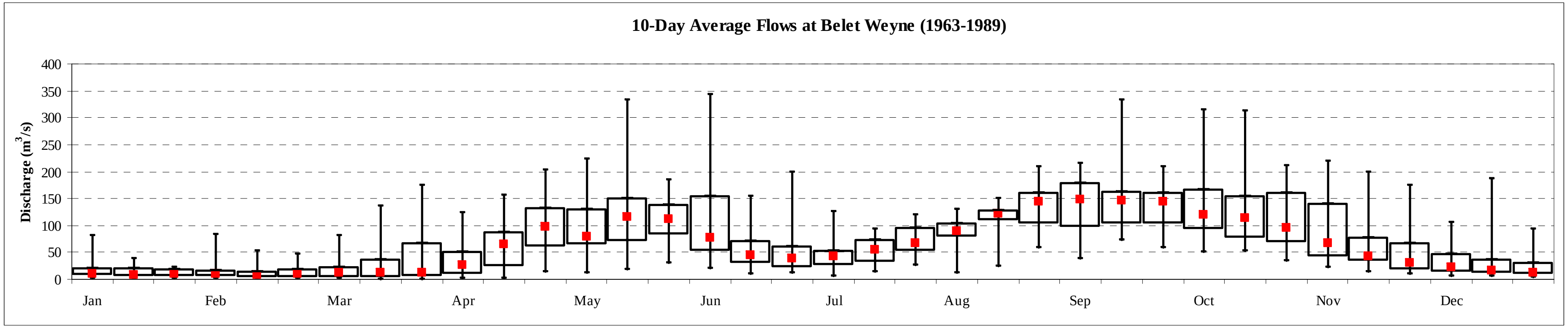
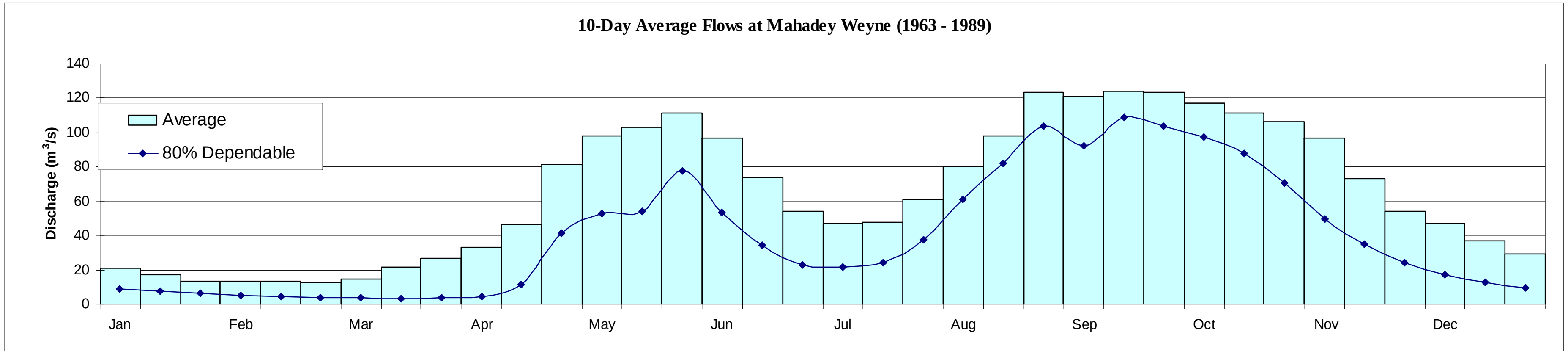
Average	17	13	12	14	12	15	20	30	39	39	64	97	97	122	113	108	57	50	45	53	72	89	110	133	140	145	133	132	122	110	93	56	51	34	35.3	25.2
80%	7	6	6	5	5	5	4	5	6	11	25	40	52	65	78	41	26	20	20	24	51	77	88	84	91	96	84	87	74	61	40	28	17	12	11.0	7.8
50%	12	11	10	14	13	14	16	19	19	36	56	73	79	115	111	76	45	38	43	55	68	89	121	143	149	145	143	119	114	95	67	43	31	21	17.2	12.7
20%	23	22	20	17	16	21	27	41	73	70	98	148	129	175	147	172	75	63	64	77	99	110	132	168	185	165	168	170	161	169	164	82	77	55	52	47





Year	Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec		
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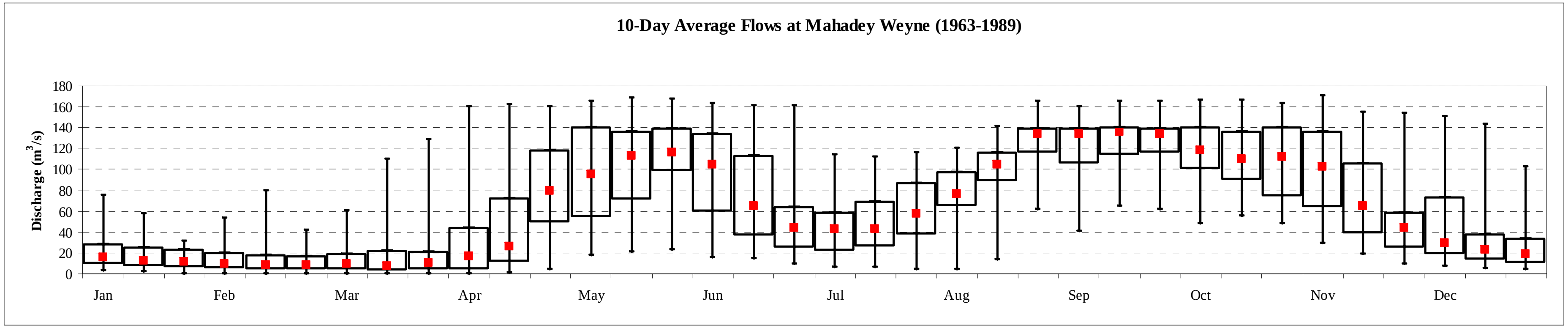
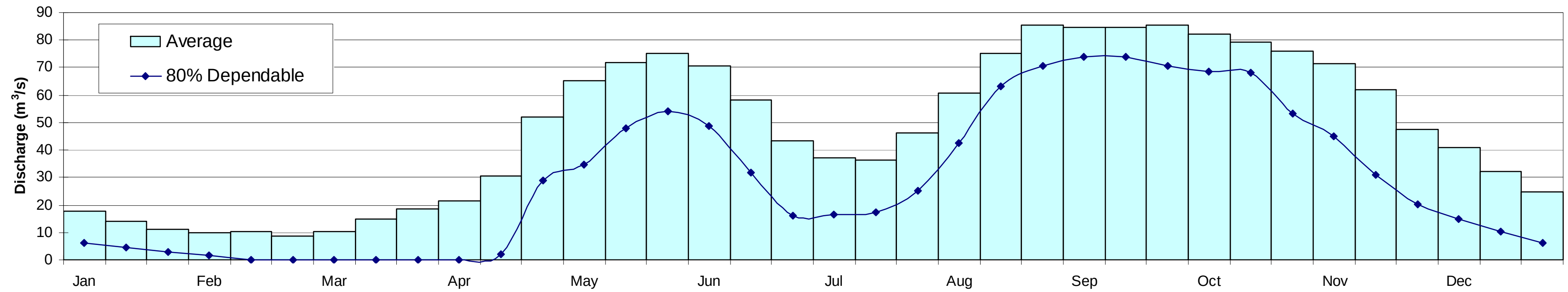
Average	21	17	14	13	13	12	14	21	27	33	46	82	98	103	112	97	74	54	47	48	61	80	98	124	121	124	124	117	111	106	97	73	54	47	37	30
80%	9	8	6	5	4	4	4	3	4	4	11	41	53	54	78	53	34	23	22	24	38	61	82	103	93	109	103	97	88	71	50	35	24	17	13	9
50%	15	13	12	13	14	12	13	15	13	22	38	65	96	113	116	104	65	44	43	43	57	77	104	134	134	136	134	118	110	112	103	65	44	29	23	19
20%	30	26	24	21	21	19	23	29	48	50	75	126	143	144	144	137	119	77	74	71	89	107	120	140	140	140	140	140	138	141	139	113	85	82	53	43



10-Day Average Flows at Afgoi (1963 - 1989)



Year	Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec		
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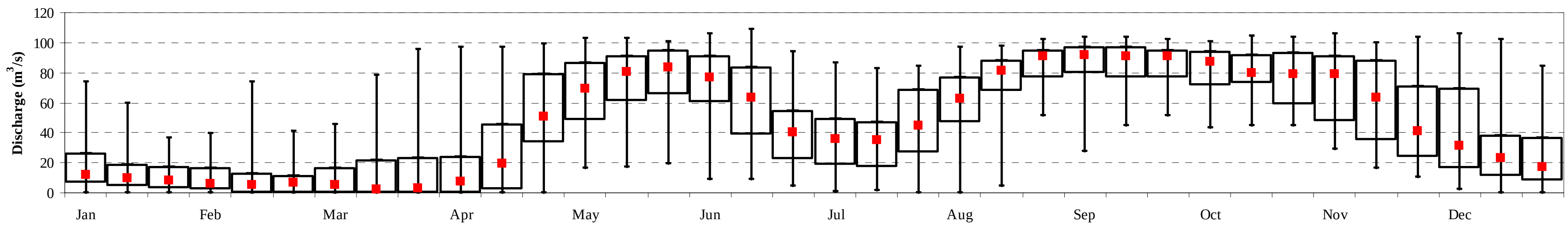
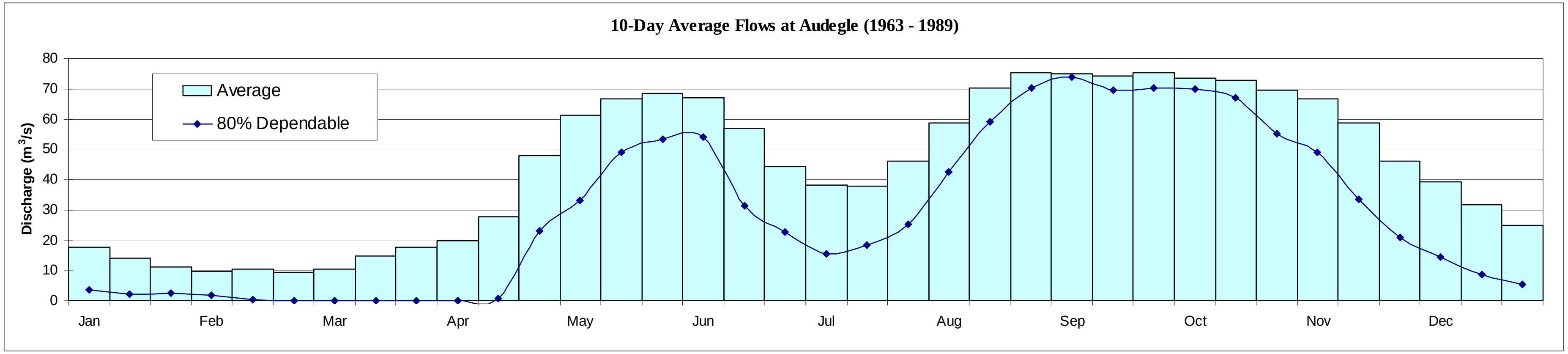
Average	18	14	11	10	10	9	10	15	19	22	31	52	65	72	75	71	58	43	37	36	46	61	75	85	85	84	85	82	79	76	71	62	48	41	32	25
80%	6	4	3	2	0	0	0	0	0	0	2	29	35	48	54	49	32	16	16	17	25	43	63	71	74	74	71	69	68	53	45	31	20	15	10	6
50%	12	10	8	8	11	8	8	11	10	16	26	47	69	81	83	77	64	41	36	35	44	63	82	91	92	91	91	87	80	79	79	64	41	32	23	17
20%	32	27	21	17	15	13	18	26	31	44	68	82	90	94	96	92	86	65	59	50	70	81	92	97	97	97	97	95	93	94	93	93	76	72	51	44

10-Day Average Flows at Afgoi (1963-1989)





Year	Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec		
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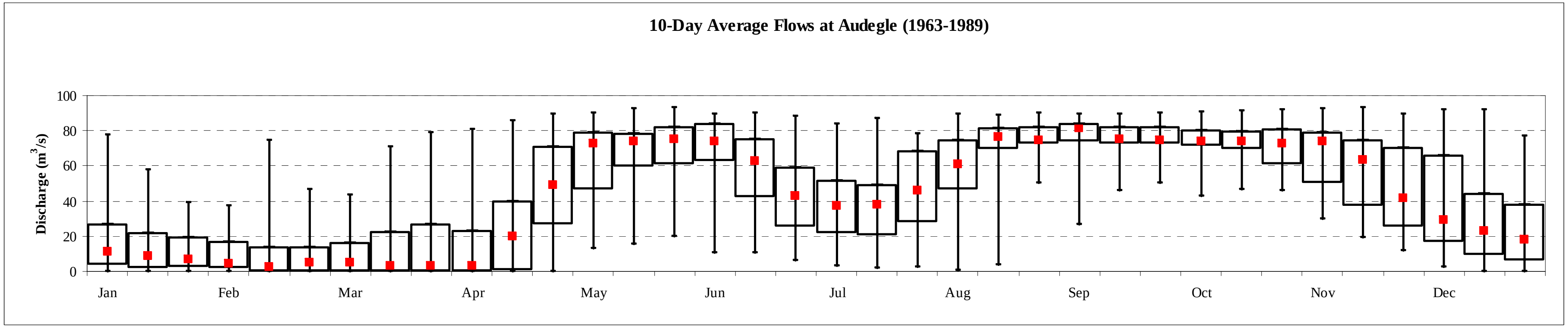
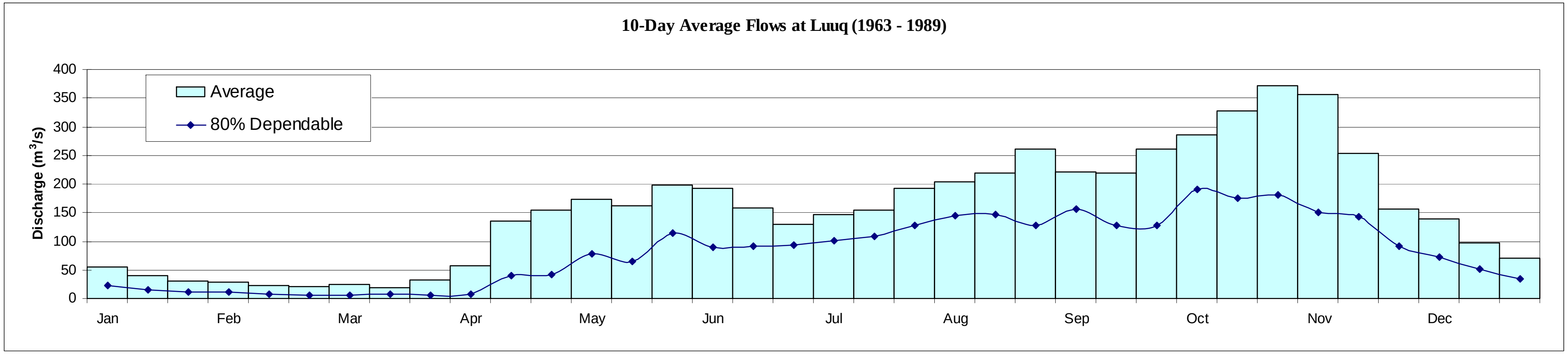
Average	18	14	11	10	10	9	10	15	18	20	28	48	61	67	68	67	57	44	38	38	46	59	70	75	75	74	75	74	73	70	67	59	46	39	32	25
80%	4	2	3	2	0	0	0	0	0	0	1	23	33	49	53	54	31	23	16	18	25	42	59	70	74	70	70	70	67	55	49	33	21	14	9	5
50%	13	9	8	6	11	7	7	12	10	17	22	45	72	74	75	74	63	43	37	38	46	61	76	74	81	75	74	74	74	72	74	63	42	29	23	18
20%	32	28	20	17	16	15	16	28	28	45	60	74	80	85	83	86	82	68	58	52	71	79	82	82	84	83	82	82	81	82	81	81	73	72	55	47





Year	Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec		
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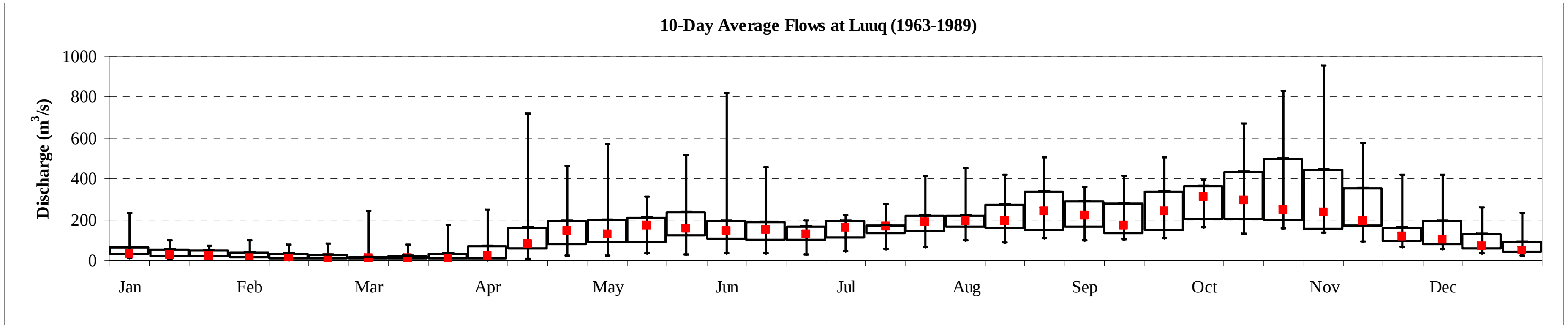
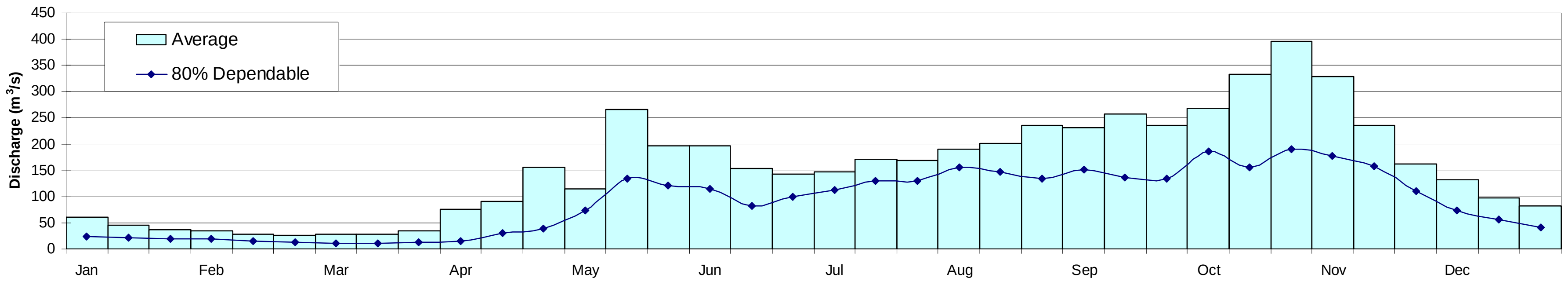
Average	55	39	30	28	23	21	25	18	32	57	134	154	173	162	197	192	159	130	147	154	192	204	218	261	221	219	261	286	327	371	356	253	156	140	97	70
80%	22	16	11	12	7	6	6	7	6	7	40	41	78	65	114	89	92	94	101	108	127	145	147	128	157	127	128	191	175	180	150	143	92	73	52	35
50%	33	27	22	23	18	15	13	14	17	33	69	131	126	172	153	146	152	126	161	166	188	194	191	239	218	173	239	309	293	246	234	193	118	101	70	47
20%	76	58	51	41	34	33	30	31	34	122	172	197	224	225	252	210	196	183	197	175	225	240	294	411	293	282	411	367	465	666	520	389	180	207	134	94



10-Day Average Flows at Bardheere (1963 - 1989)



Year	Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec		
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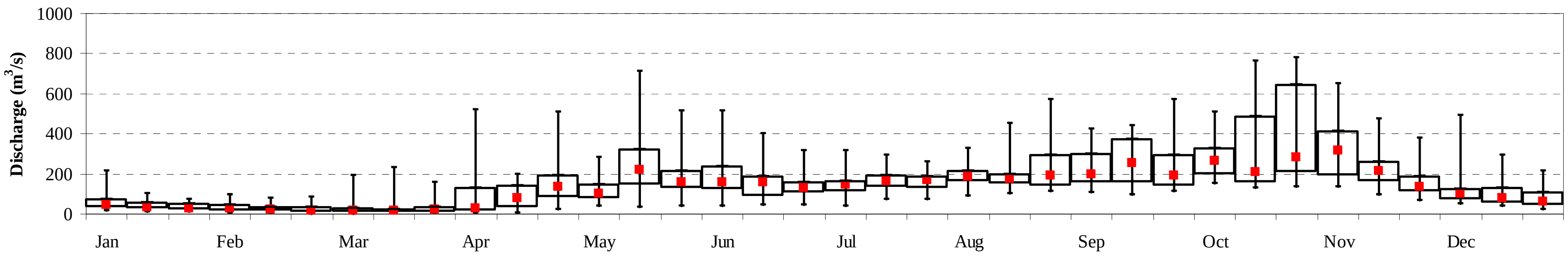
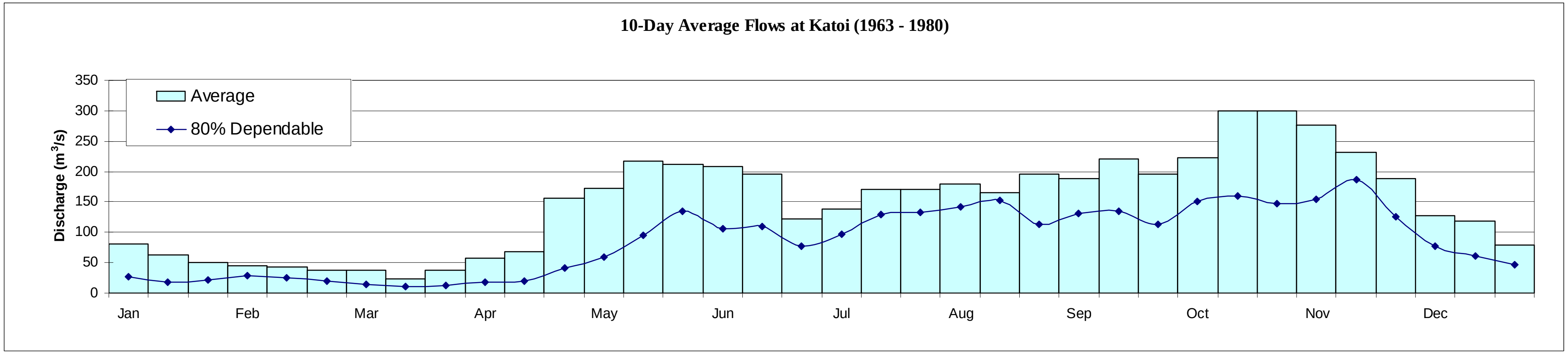
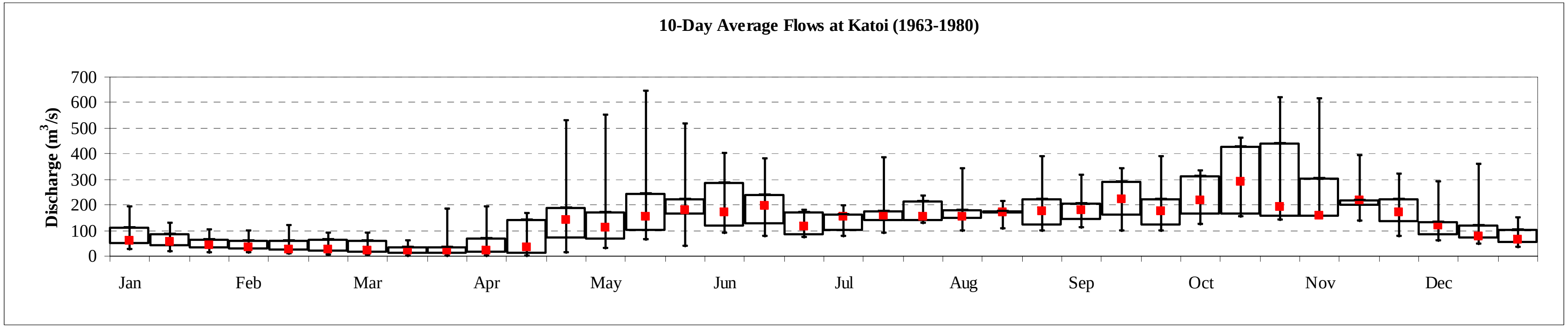
Average	62	45	36	35	28	27	28	29	34	75	90	155	115	265	196	197	153	142	147	172	169	191	200	236	231	257	236	269	334	396	329	236	163	132	97	82
80%	24	21	20	19	15	13	11	11	13	15	31	40	74	134	120	115	82	100	112	129	130	155	148	134	152	136	134	187	157	189	177	158	110	74	55	42
50%	42	32	25	29	25	22	19	17	21	32	59	113	101	219	161	159	159	130	147	165	169	187	173	194	199	253	194	268	208	282	319	215	137	104	77	62
20%	85	67	57	49	38	37	37	32	39	144	140	216	148	343	239	242	191	164	168	223	195	217	219	310	314	372	310	328	543	692	472	293	191	138	138	117

10-Day Average Flows at Bardheere (1963-1989)

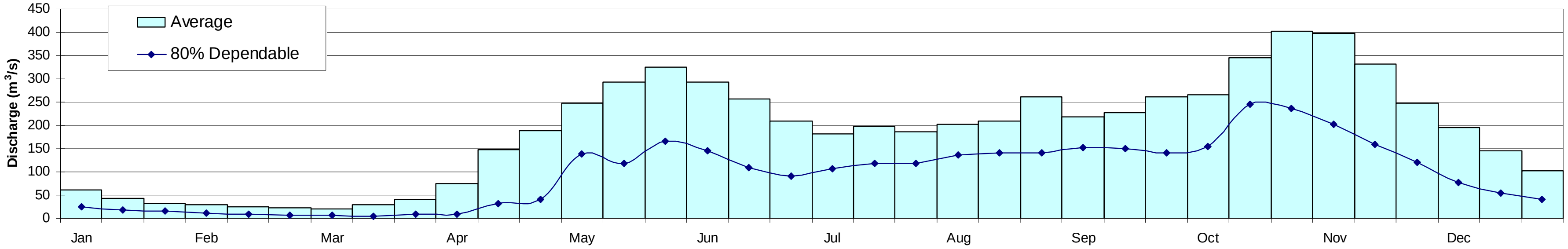




Year	Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Average	81	63	50	45	43	38	37	24	37	58	68	155	172	218	212	209	196	122	138	171	170	180	166	196	188	221	196	222	299	300	277	232	188	127	118	78
80%	27	19	22	28	25	20	14	11	12	18	20	41	59	94	135	107	110	76	97	130	133	143	153	112	131	135	112	151	159	147	155	186	126	76	60	47
50%	47	39	38	52	54	31	27	37	36	51	38	82	111	152	180	170	196	116	152	158	154	156	169	174	180	220	174	218	291	191	157	216	172	120	78	65
20%	127	97	79	61	72	69	64	38	41	71	146	211	224	277	265	322	265	171	167	179	217	188	184	228	214	312	228	314	435	516	364	252	265	135	137	119

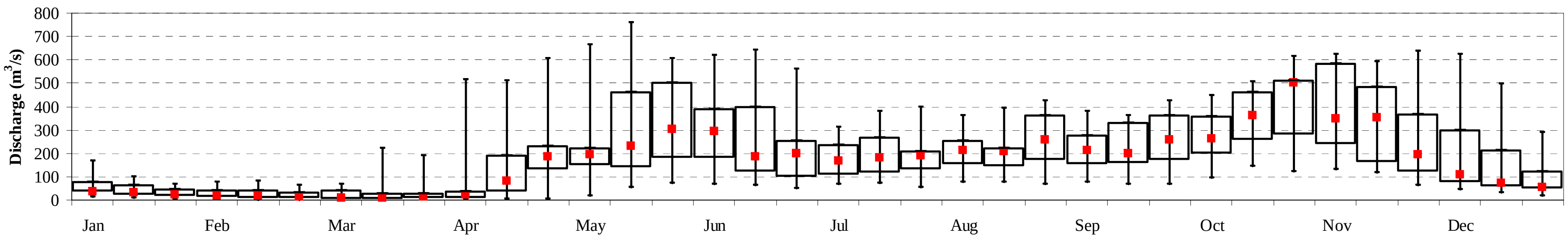


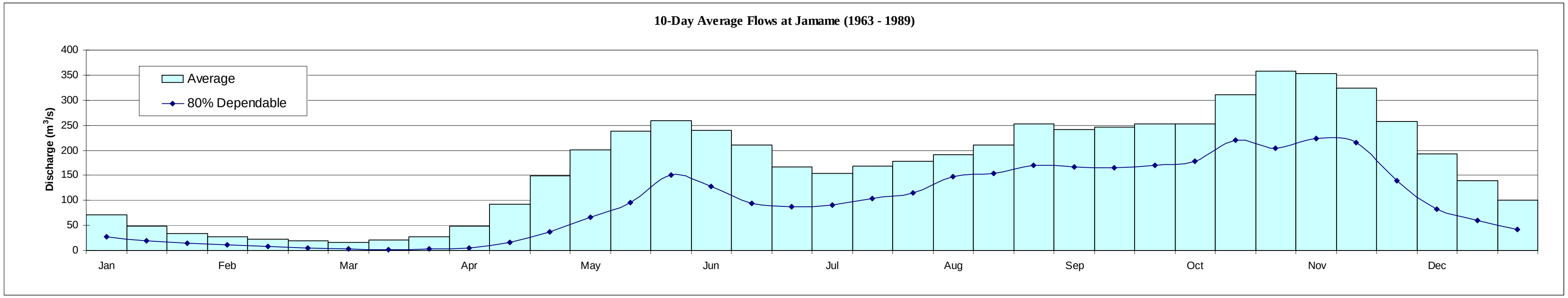
10-Day Average Flows at Mareere (1977 - 1989)



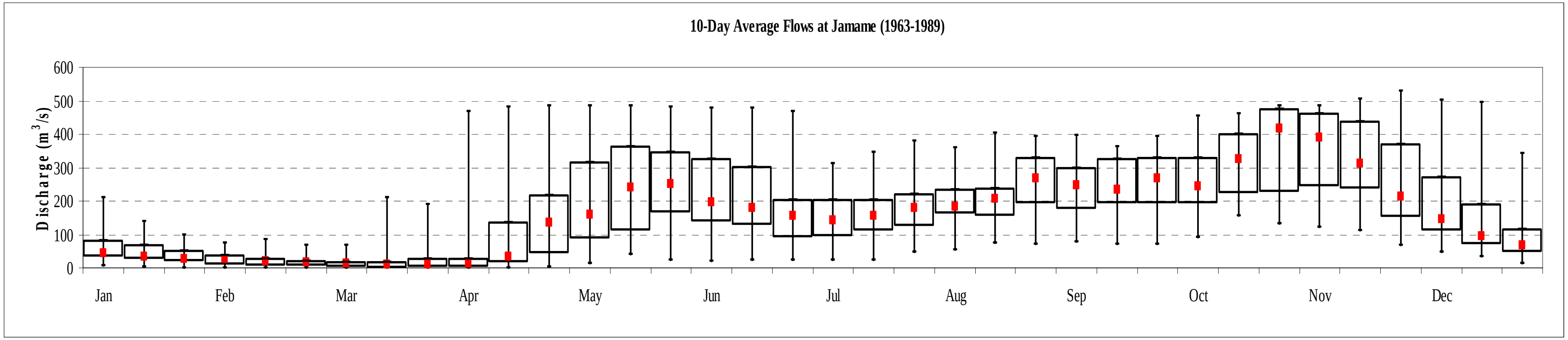
Year	Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Average	62	43	32	29	26	22	20	30	40	75	148	188	248	294	325	294	256	209	182	197	187	202	209	262	219	228	262	266	344	403	398	333	247	195	145	103
80%	26	18	16	12	9	7	6	4	9	10	31	41	139	118	166	146	110	92	107	118	118	136	142	140	152	150	140	154	246	236	202	160	120	77	55	41
50%	36	26	22	36	33	23	16	22	23	32	68	135	194	229	305	294	184	197	167	180	191	211	206	258	212	197	258	261	362	504	348	352	196	107	71	56
20%	90	67	51	50	45	43	41	34	37	95	233	245	380	477	508	443	405	257	263	281	222	255	257	383	282	336	383	377	472	524	587	484	373	312	237	160

10-Day Average Flows at Mareere (1977-1989)





Year	Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Average	71	48	34	27	23	19	17	20	27	49	93	149	200	238	259	239	210	166	154	169	178	192	211	253	242	246	253	253	311	358	353	323	257	193	139	101
80%	27	19	15	12	8	6	4	1	3	5	15	37	67	95	151	129	94	87	91	103	115	147	153	170	167	165	170	178	221	205	224	215	139	83	60	43
50%	39	30	24	27	24	18	13	12	13	20	38	102	158	242	252	195	180	158	141	156	179	182	205	267	246	235	267	245	326	418	391	313	214	145	96	66
20%	92	70	51	40	33	24	36	28	30	37	167	225	388	388	407	379	308	243	213	256	235	244	245	345	308	344	345	343	404	477	472	445	379	297	216	125



Annex B : Pre-war Irrigation Infrastructure

Annex B.1: Barrages in Juba and Shabelle Rivers

		Year	District	Command Area (ha)		No of Gates	Canal Systems Supplied	Aerial Photographs - Tile Index
				Pre-war	Potential			
	Juba							
1	Fanoole	1977/82	Bualle/Jilb	15,250	120,000			SH-25-427
	Shabelle							
1	Sabuun	1925	Jowhar	50,942		9	FAO/Sabuun Canal	SH-25-229
2	Balcad	Little information available						SH-25-053
3	Janaale/ Genale	1927	Qorooley/ Marka	67,400		11	- Cessare Maria (Primo Primario) including Primo Secondary (Left Bank)	SH-25-111
							- Asayle canal (Right Bank)	
							- Flood diversion through Cessare Maria to the dunes near Sinay and thru Primo Secondario to the Shangaani basin through the Gofca channel	
							Others - Giddu, Sigale East and West, Degwariri, Jiidow and Busley	
4	Mashalay	1986	Qorooley/Marka				Promo Secondario	
5	Qorooley	1955	Qorooley	4,210		9	Fomar (Wadajir), Libaan 20 small canals	SH-25-084
6	Falkeero	1955	Qorooley			9	Bakooro, Furuqulay and Barawaqo and small canals	SH-25-097
7	Kurtinwarey	1986	Kurtunwareey	5,000		8	Irrigation schemes in villages of Garawlay, Uranurow, Sheikh nananey and AFgoi Yare	SH-25-170
8	Sablaale	1987	Sablaale				Sablaale irrigation settlements scheme	SH-25-020
9	Haway	1926		3,000			Haway irrigation scheme	SH-25-004

Annex B.2:Pre-war Irrigation Schemes in Juba River Basin

	Name	Pre-war	Potential	Corresponding Barrage/Weir	Corresponding Canal	District	Region	Cropping Pattern	Status
1	Fanoole Rice Irrigation Scheme (I & II)	1,800	8,200	Fanoole		Bu'aale & Jilib	Middle Juba		Not Functioning
2	Homboy Settlement Irrigation Project	14,318				Jamaame & Jilib	Lower & Middle Juba		Not Functioning
3	Juba (Mareerey) Sugar Project (1987)	7,000	10,720			Afmadow, Jamaame & Jilib	Lower & Middle Juba	sugarcane	Partial with extension
4	Mogambo Irrigation Project (1986)	2,364	9,800			Jamaame	Lower Juba	rice, bananas	Not Functioning
5	Banana Estates (Medium Pump Schemes)	3,400	4,470			Jamaame & Kismayo	Lower Juba		Partial
6	Pumping (140 @ 170 l/s capacity)	3,400							

Annex B.3: Pre-war Irrigation Schemes in Shabelle River Basin

	Scheme	Pre-war	Potential	Corresponding Barrage/Weir	Correspond-ing Canal	District	Region	Cropping Pattern	Status
1	Military Farm/Crash Program	1,435		None		Beletweyn	Hiraan	Maize, Sesame, Soghum	Partial
2	Barroweyne (1982)	180	4,200	Sabuun		Jowhar	Middle Shabelle	Rice, Maize	Partial
3	Jowhar Sugar Estate (1920)	10,579	32,357	Sabuun		Jowhar & Balcad	Middle Shabelle	Sugarcane	Partial
4	Iraqsome cotton project - Balcad Flood Irrigation Project (1967)	10,000	14,700	Balcad		Balcad/ Afgoi	Middle/ Lower Shabelle	Cotton, Sesame, Maize	
5	Afgoi-Mordile Project (1967)	1,560	19,365	Balcad		Afgooye	Lower Shabelle	Banana, sugarcane, cotton	Partial
6	Agricultural Research Centre (1967)	1,561	4,500	Balcad		Afgooye	Lower Shabelle	Banana, grapefruit, sorghum, sugarcane, cotton, oilseeds, vegetables	Partial
7	Genale Bulo-Marerta Irrigation Schemes	**54,180**	**67,410**						
7.1	Asayle Project	4,563		Genale	Asayle	Qoryooley	Lower Shabelle		Partial
7.2	Genale Development Zone	9,221		Genale	Dhamme Yasin	Qoryooley & Merka	Lower Shabelle		Partial

	Scheme	Pre-war	Potential	Corresponding Barrage/Weir	Correspond-ing Canal	District	Region	Cropping Pattern	Status
7.3	Degwariiri Zone	6,748			Sigaale and Giddu	Qoryooley	Lower Shabelle		Partial
7.4	Bandar Development Zone	2,929				Qoryooley	Lower Shabelle		Not Functioning
7.5	Banana Drainage Project	3,884				Qoryooley & Merka	Lower Shabelle	Banana	partial
7.6	Der Flood Project	862				Qoryooley	Lower Shabelle		Not Functioning
7.7	EDF Grapefruit production scheme	2,065				Merka	Lower Shabelle	Banana, grapefruit	Not Functioning
7.8	Faraxaane (Farahane) Project	4,883				Qoryooley & Merka	Lower Shabelle	Sesame. Maize	Not Functioning
7.9	Golweyn Project	3,313				Merka	Lower Shabelle		Partial
7.10	Haduuman Zone	1,960				Qoryooley	Lower Shabelle		Partial
7.11	Jeerow Zone	2,325	9,686			Kurtunwarey & Qoryooley	Lower Shabelle		Partial
7.12	Majabto Zone	1,628				Qoryooley	Lower Shabelle		Partial
7.13	Mukoy Dumis Project	9,132				Kurtunwarey & Merka	Lower Shabelle		Partial
7.14	Primo Secondario Banana Zone	3,956				Qoryooley & Merka	Lower Shabelle		Partial
7.15	Qoryooley Project	6,379		Mashallay	Asayle	Qoryooley	Lower Shabelle		Partial

	Scheme	Pre-war	Potential	Corresponding Barrage/Weir	Correspond-ing Canal	District	Region	Cropping Pattern	Status
7.16	Shalambood Project	6,993				Merka	Lower Shabelle		Partial
7.17	Tahliil Zone	2,903				Qoryooley & Merka	Lower Shabelle		Partial
7.18	Waagade Zone	3,461				Merka	Lower Shabelle		Partial
8	Refugee Farm	5,487	6,060	Falkerow		Kurtunwarey & Qoryooley	Lower Shabelle		Not functioning
9	Kurtunwareey Irrigation Scheme (1986)	4,900	29,742	Kurtunwareey		Kurunwareey		Maize, Sesame and Sunflower	Partial
10	Sabalaale (Farjano) Irrigation Settlement Scheme	16,000	28,740	Sablaale		Sablale & Barawe	Lower Shabelle	Bananas, fruit trees	Partial
11	Haway Irrigation Settlement Scheme	395	400					Maize, Sesame, Vegetables, Water Melon, Tobacco	

Annex B.4: Pre-war Irrigated Areas and Cropping Pattern on the Shabelle Flood Plain

	District	Crop	Year 1979 (ha)				Proposed (ha)			
			Gu	Der	Perennial	Total	Gu	Der	Perennial	Total
1	Jalalaqsi	Sisal							400	400
2	Jowhar	Maize	210	50			625			
		Groundnuts	100				425			
		Cotton		100				425		
		Paddy Rice		50				415		
		Sesame		120				410		
		Pulses					200			
						320				**1,250**
3	Jowhar Sugar	Sugarcane			6,150				7,750	
		Citrus			50				50	
						6,200				**8,000**
	Total above Jowhar		**310**	**320**	**6,200**	**6,520**	**1,250**	**1,250**	**8,200**	**9,650**
4	Balad Cotton	Maize	360				2,380			
		Cotton		700				5,600		
		Sesame		300				2,400		
						1,000				**8,000**
5	Balad/Audegle	Maize	3,500	1,000			4,500	1,250		
		Sesame		3,500				4,500		
		Pulses/Vegetables	1,500	500			2,000	750		
		Cotton		1,200				1,500		
		Bananas			350				350	
		Citrus			80				150	
		Miscallaneous							400	
						6,630				**8,900**
6	Afgoi/Mordiile	Maize	802				2,140			

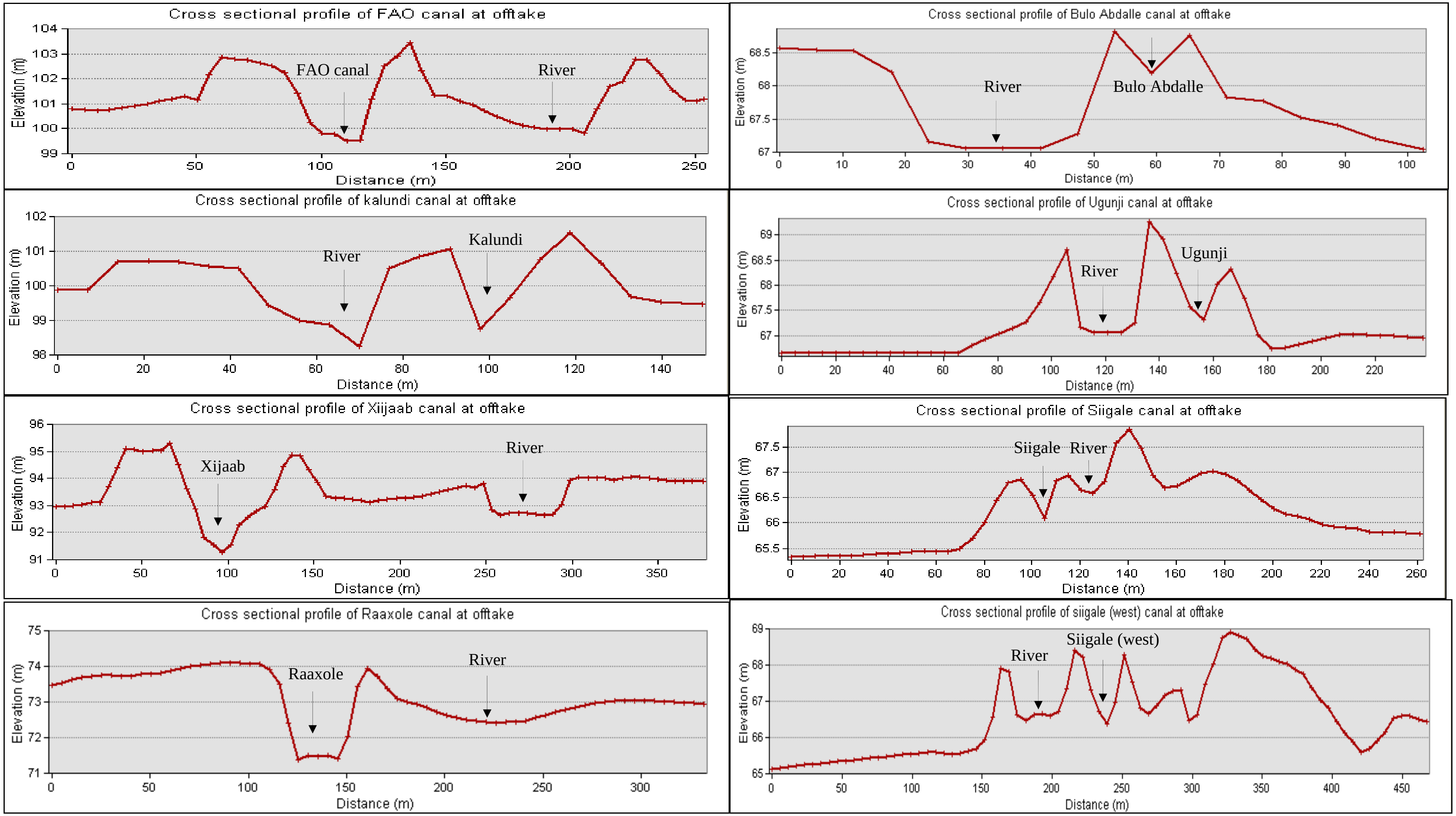
	District	Crop	Year 1979 (ha)				Proposed (ha)			
			Gu	Der	Perennial	Total	Gu	Der	Perennial	Total
		Groundnuts	536				1,430			
		Upland Rice	160	320			430	860		
		Sesame		320				860		
						1,500				**4,000**
7	Janaale/Bulo Mareeria	Maize	16,090	9,620			15,357	6,823		
		Sesame		9,450				9,524		
		Upland Rice	500				1,293	793		
		Bananas			4,065				4,650	
		Citrus			200				1,585	
		Miscallaneous			105				105	
		Cotton						1,387		
		Forage					793			
						20,960				**24,867**
8	Kurten-Waarey	Maize	340				1,800	600		
		Upland Rice	30	185				1,200		
		Pulses					600			
		Sesame		185				600		
		Bananas			30					
		Miscallaneous			165					
						565				**2,400**
9	Sablaale	Maize	320				1,800	600		
		Pulses	220	150			600			
		Paddy Rice	50	220				1,200		
		Sesame		440				600		
		Sorghum	220							
		Bananas			30					
		Miscallaneous			160					
						1,000				**2,400**

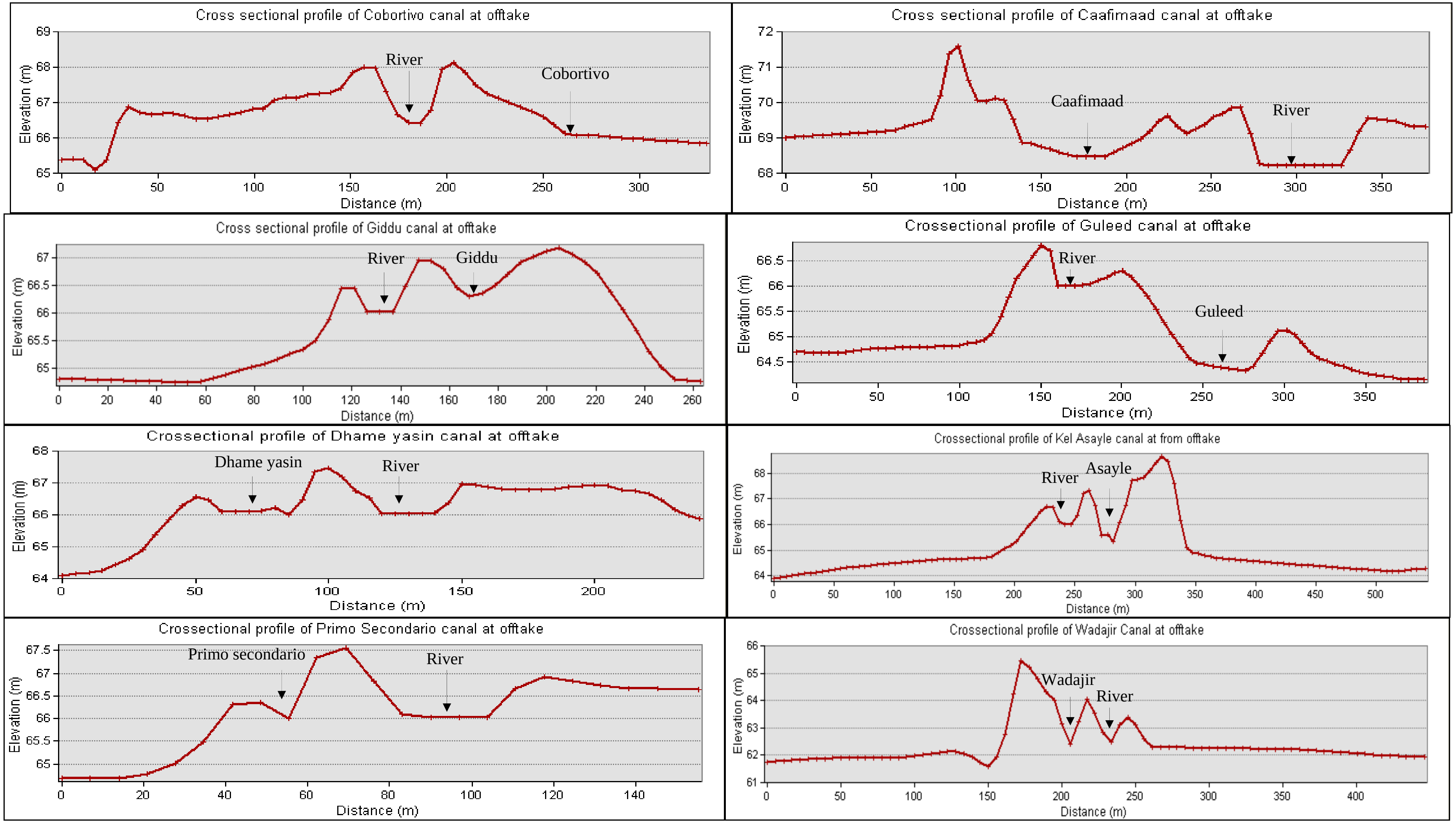
	District	Crop	Year 1979 (ha)				Proposed (ha)			
			Gu	Der	Perennial	Total	Gu	Der	Perennial	Total
10	Haawaay	Maize	200				2,500			
		Paddy Rice		500				5,000		
						500				**5,000**
	Total Below Jowhar		**24,828**	**28,590**	**5,185**	**32,155**	**37,623**	**46,047**	**7,240**	**55,567**
	Grand Total		**25,138**	**28,910**	**11,385**	**38,675**	**38,873**	**47,297**	**15,840**	**65,617**

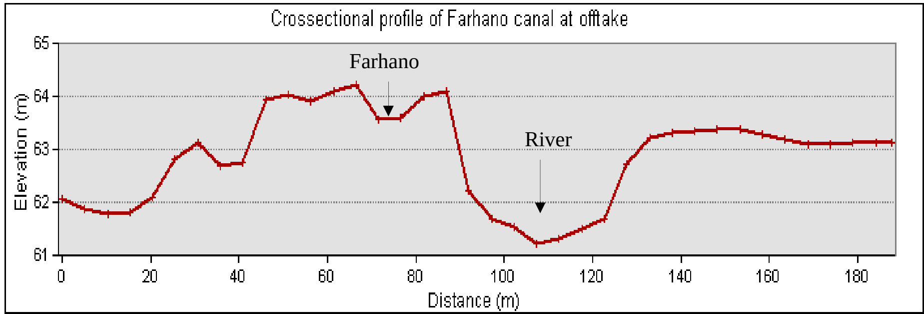
Source:
Henry, J. C. "Present and Future Irrigated Agriculture in the Shebelle and Juba River Basins, Dem. Rep. of Somalia, FAO, Rome 1979

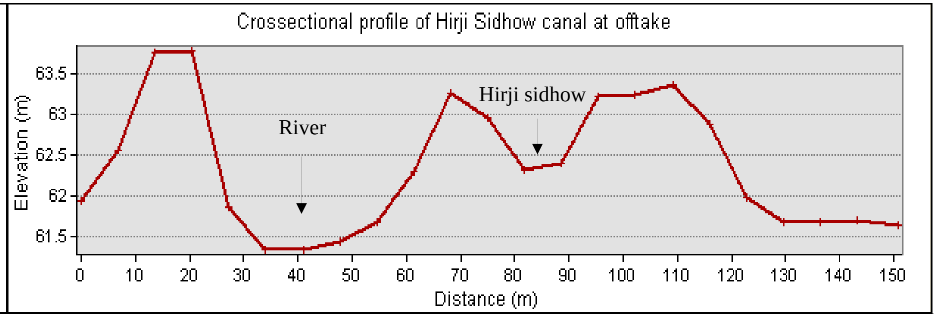
Annex C : Mapping of Primary Irrigation Canals

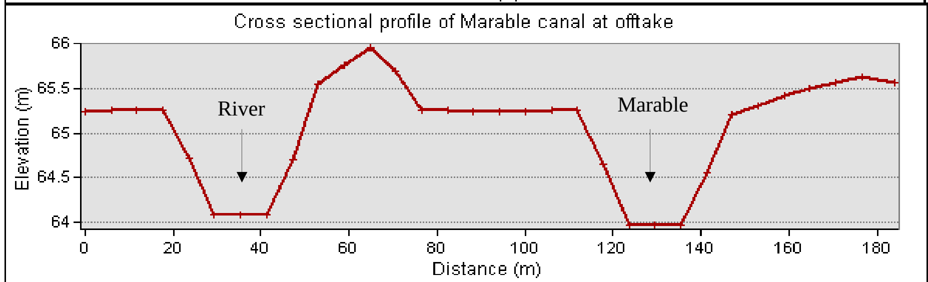
Annex C.1: Cross-sectional Profiles of Primary Canals along River Shabelle in Middle and Lower Shabelle Regions

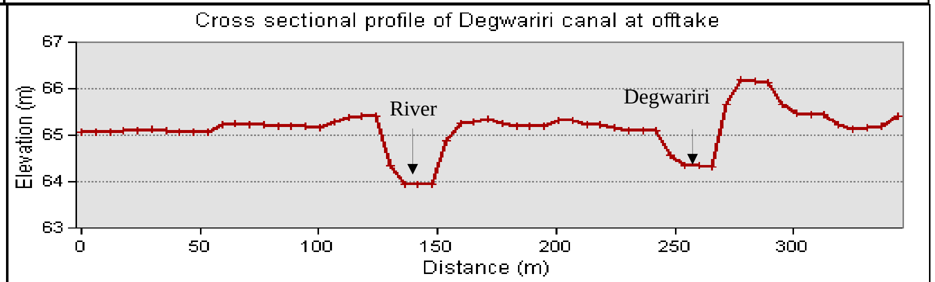


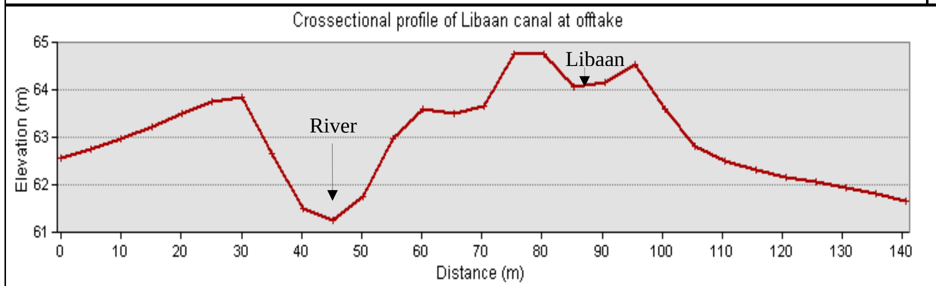

Cross sectional profile of Cobortivo canal at offtake
River
Cobortivo
Elevation (m)
Distance (m)
Cross sectional profile of Caafimaad canal at offtake
Caafimaad
River
Elevation (m)
Distance (m)
Cross sectional profile of Giddu canal at offtake
River
Giddu
Elevation (m)
Distance (m)
Crossectional profile of Guleed canal at offtake
River
Guleed
Elevation (m)
Distance (m)
Crossectional profile of Dhame yasin canal at offtake
Dhame yasin
River
Elevation (m)
Distance (m)
Crossectional profile of Kel Asayle canal at from offtake
River
Asayle
Elevation (m)
Distance (m)
Crossectional profile of Primo Secondario canal at offtake
Primo secondario
River
Elevation (m)
Distance (m)
Crossectional profile of Wadajir Canal at offtake
Wadajir
River
Elevation (m)
Distance (m)

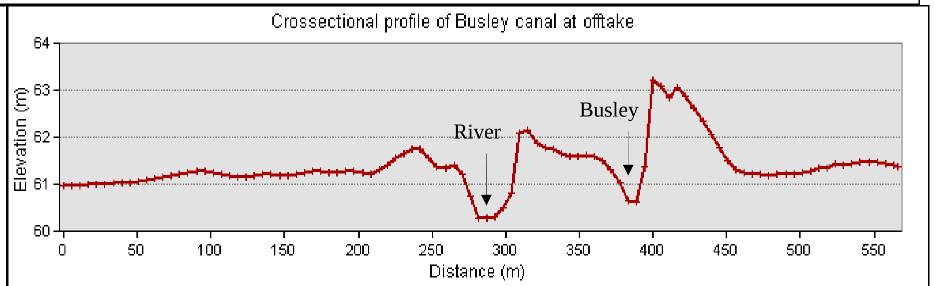

Crossectional profile of Farhano canal at offtake
Farhano
River
Elevation (m)
65
64
63
62
61
0
20
40
60
80
100
120
140
160
180
Distance (m)

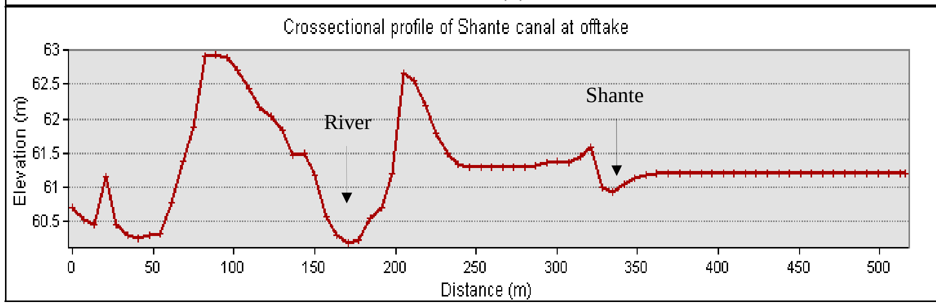

Crossectional profile of Hirji Sidhow canal at offtake
Hirji sidhow
River
Elevation (m)
63.5
63
62.5
62
61.5
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Distance (m)

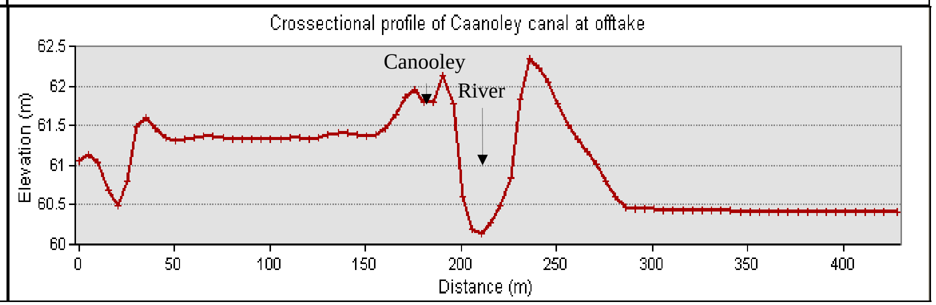

Cross sectional profile of Marable canal at offtake
River
Marable
Elevation (m)
66
65.5
65
64.5
64
0
20
40
60
80
100
120
140
160
180
Distance (m)

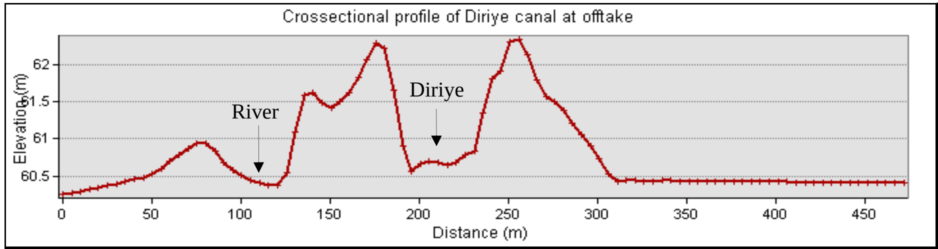

Cross sectional profile of Degwariri canal at offtake
River
Degwariri
Elevation (m)
67
66
65
64
63
0
50
100
150
200
250
300
Distance (m)

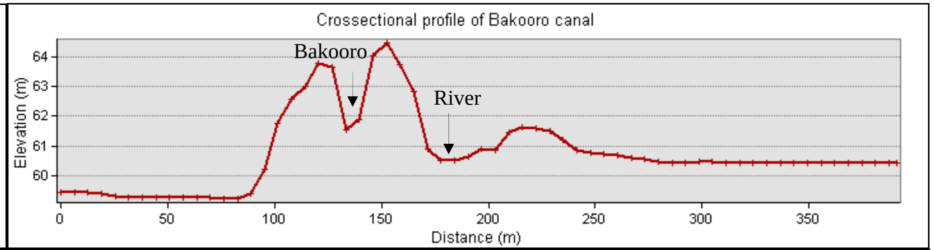

Crossectional profile of Libaan canal at offtake
Libaan
River
Elevation (m)
65
64
63
62
61
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Distance (m)

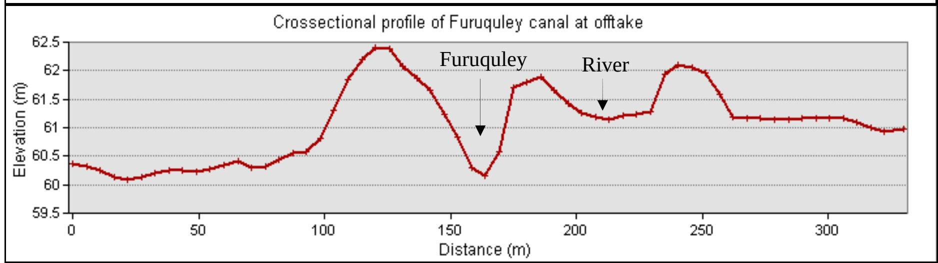

Crossectional profile of Busley canal at offtake
Busley
River
Elevation (m)
64
63
62
61
60
0
50
100
150
200
250
300
350
400
450
500
550
Distance (m)

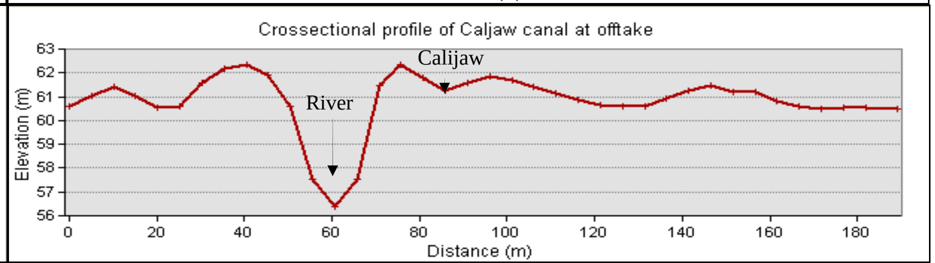

Crossectional profile of Shante canal at offtake
Shante
River
Elevation (m)
63
62.5
62
61.5
61
60.5
0
50
100
150
200
250
300
350
400
450
500
Distance (m)

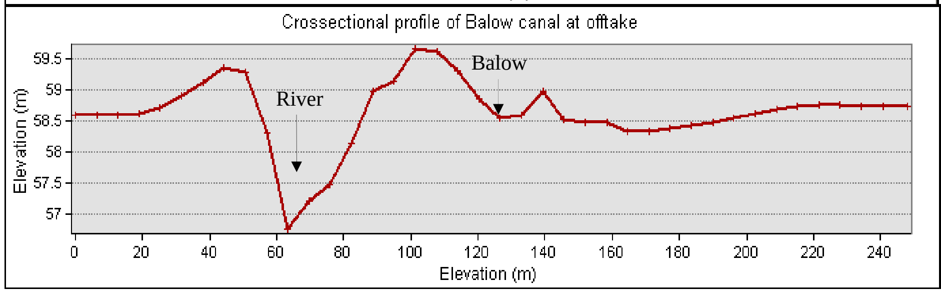

Crossectional profile of Caanoley canal at offtake
Canooley
River
Elevation (m)
62.5
62
61.5
61
60.5
60
0
50
100
150
200
250
300
350
400
Distance (m)

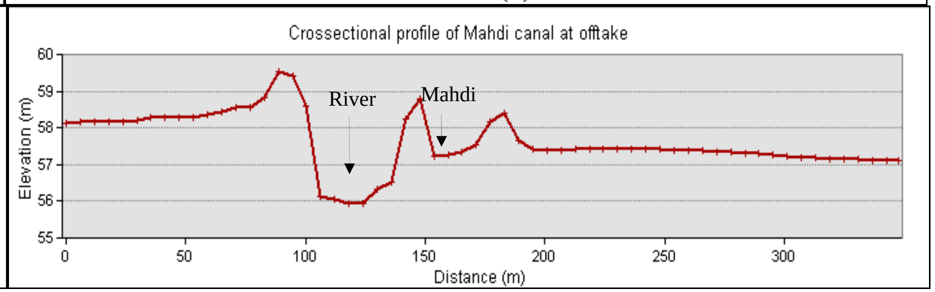

Crossectional profile of Diriye canal at offtake
River
Diriye
Elevation (m)
Distance (m)

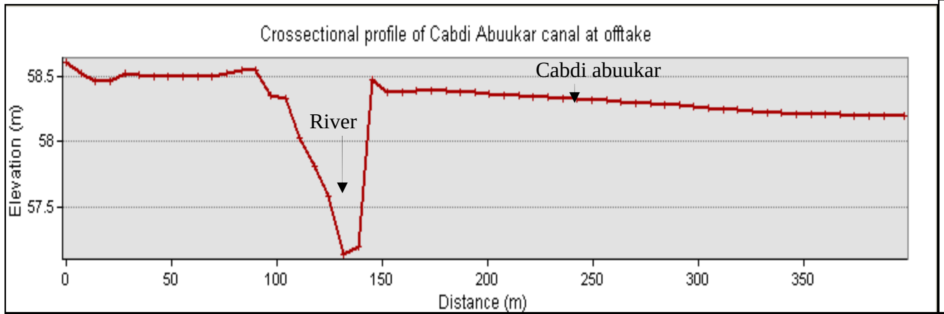

Crossectional profile of Bakooro canal
Bakooro
River
Elevation (m)
Distance (m)

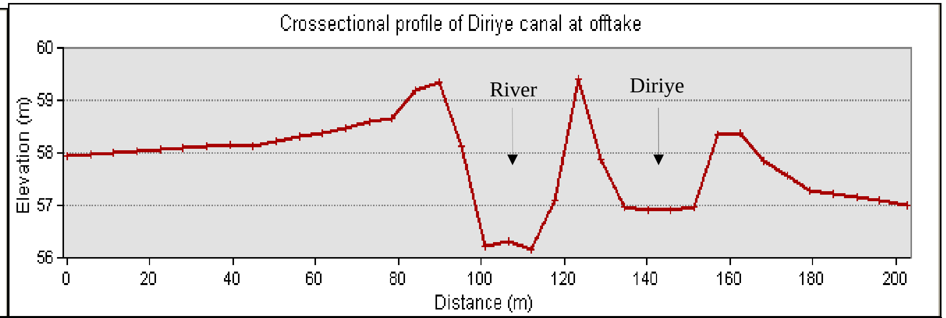

Crossectional profile of Furuquley canal at offtake
Furuquley
River
Elevation (m)
Distance (m)

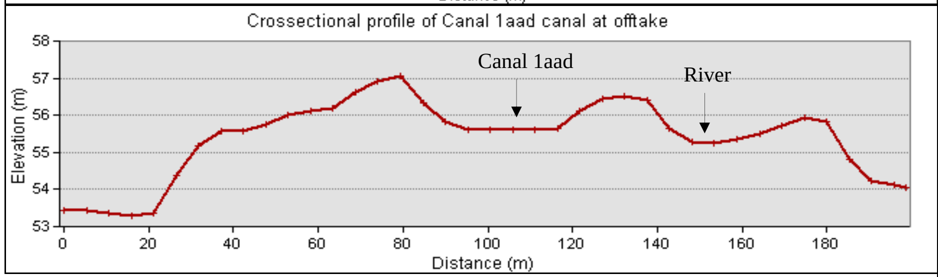

Crossectional profile of Caljaw canal at offtake
Calijaw
River
Elevation (m)
Distance (m)

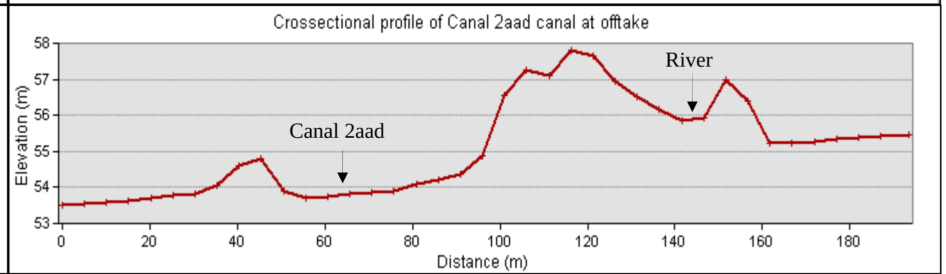

Crossectional profile of Balow canal at offtake
Balow
River
Elevation (m)
Elevation (m)

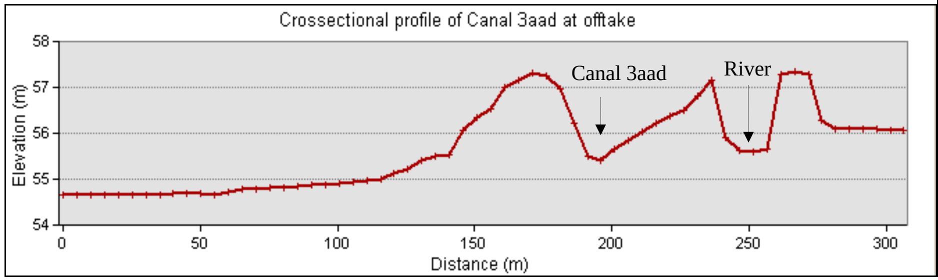

Crossectional profile of Mahdi canal at offtake
River
Mahdi
Elevation (m)
Distance (m)

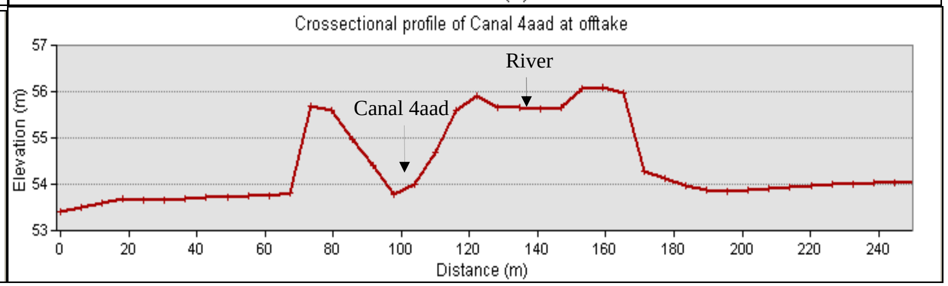

Crossectional profile of Cabdi Abuukar canal at offtake
Cabdi abuukar
River
Elevation (m)
Distance (m)


Crossectional profile of Diriye canal at offtake
River
Diriye
Elevation (m)
Distance (m)

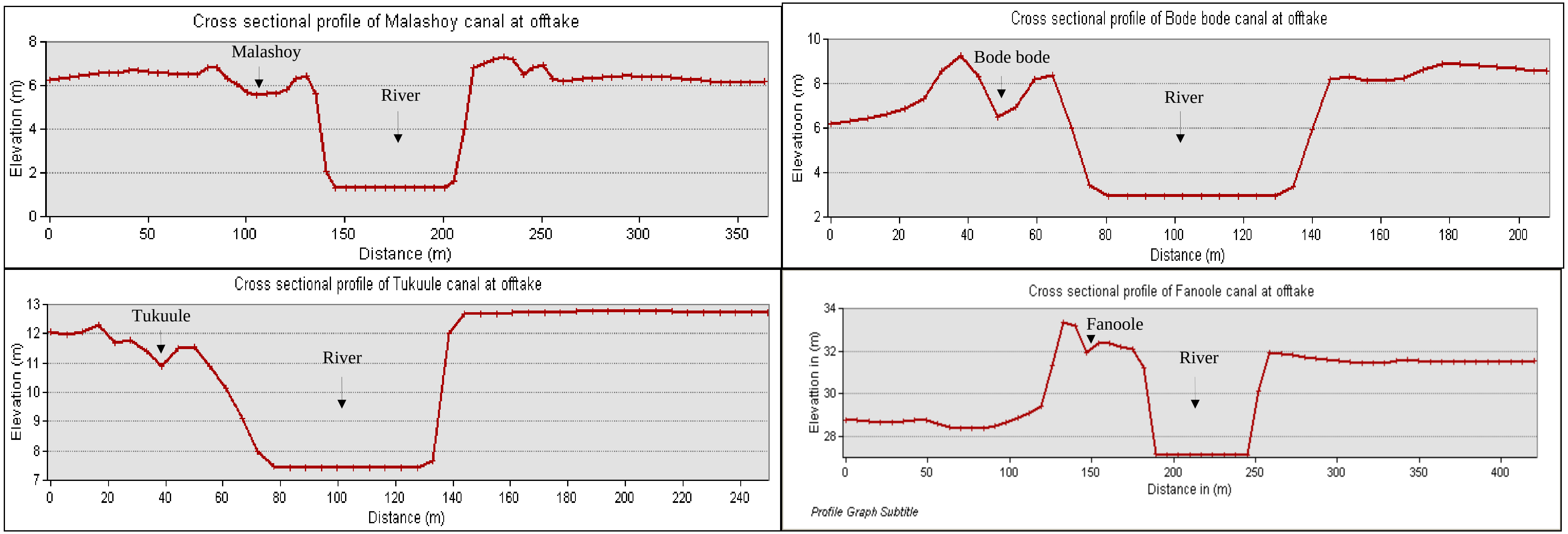

Crossectional profile of Canal 1aad canal at offtake
Canal 1aad
River
Elevation (m)
Distance (m)


Crossectional profile of Canal 2aad canal at offtake
River
Canal 2aad
Elevation (m)
Distance (m)


Crossectional profile of Canal 3aad at offtake
Canal 3aad
River
Elevation (m)
Distance (m)


Crossectional profile of Canal 4aad at offtake
River
Canal 4aad
Elevation (m)
Distance (m)

Annex C.2: Cross-sectional Profiles of Selected Primary Canals along Juba River



Annex C.3: Summary of Primary Canals Profiles Extracted

Canal Name	**At off take point from the River**	**At 500m from off take**
River Shabelle	**Depth (m)**	**Depth (m)**
FAO canal	2.91	0.01
kalundi	2.29	1.74
Xiijaab	3.61	1.54
Raaxole	2.12	2.12
Corbortivo	0.07	0.02
Bulo Abdalle	0.58	0.47
Ugunji	0.92	0.6
kel General Daud	1.14	0.5
siigale	0.76	0.24
Siigale West	1.84	2.02
Caafimaad	1.07	0.33
Giddu	0.62	0.24
Dhame yasin	0.73	0.69
Primo secondario	0.3	0.27
Farhano	0.45	0.78
marable	1.15	1.03
Guleed	0.12	0.03
Asayle	1.86	0.68
Wadajir	1.61	0.88
Hirji Sidhow	0.65	0.52
Degwariri	0.77	0.32
Libaan	0.47	0.13
Shante	0.3	0.09
Furuquley	1.5	0.88
Diriye	0.52	0.04
Balow	0.2	0.13
Busley	0.89	0.71
Caanoley	0.14	0.54
Bakooro	2.05	1.54
Calijaw	0.6	0.93
Mahdi	0.68	0.73
Cabdi Abuukar	0.11	0.09
Canal 1aad	0.5	0.13
Canal 2aad	0.66	0.76
Canal 3aad	1.54	0.06
Canal 4aad	1.61	0.51
River Juba		
Fanoole	0.46	1.19
Tukuule	0.52	1.76
Malashoy	0.37	1.65
Bode Bode	1.7	2.14

Annex C.4: Sample Orthophoto near the Janaale Barrage[14]

[14] Ortho-photos together with the DTM were used for Profile Generation of Primary Canal off-takes