Improving Flood Forecasting and Early Warning in Somalia

Feasibility Study

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[1] SAIC, contractor to U.S. Geological Survey, Centre for Earth Resources Observation and Science (EROS), Sioux Falls, SD 57198 USA (work performed by SAIC under USGS contract 03CRCN0001)

List of Abbreviations

ADCP	Acoustic Doppler Current Profiler
CEFA	Comitato Europeo per la Formazione e l'Agricoltura
CFMC	Community Flood Management Committees
DEM	Digital Elevation Model
EMWR	the Ethiopian Ministry of Water Resources
EROS	Earth Resources Observations and Science
FAO	Food and Agriculture Organisation of United Nations
FEWS NET	Famine Early Warning System Network
FFC	Flood Forecasting Centre
FFG	Flash Flood Guidance
FSAU	Food Security Analysis Unit - Somalia
FSDRSC	Food Security and Rural Development Sector Committee of the SSS
FWG	Flood Working Group
GAA	German Agro-Action
GFFS	Galway Real-Time River Flow Forecasting System
GFFS	Galway Real-Time River Flow Forecasting System
GFS	Global Forecast System
GFS	Global Forecast System
GSM	Global System for Mobile
GTS	Global Telecommunication System
ITCZ	Inter tropical Convergence Zone
JOSR	Jowhar off Stream Storage Reservoir
KMD	Kenya Meteorological Department
LVGFM	Linearly Varying Gain Factor Model
MoA	Ministry of Agriculture
MOFFS	Management Overview of Flood Forecasting System
MOLAE	Ministry of Livestock, Agriculture and Environment
MPWT	Ministry of Public Works and Transportation
NCEP	National Centres for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Services
NWS	National Weather services
PET	Potential Evapotranspiration
QPF	Quantitative Precipitation Forecast
RFE	Rainfall Estimates
RFFCs	Regional Flood Forecast Centres
SFFM	Somalia Flood Forecasting Model
SSS	Somali Support Secretariat
SWALIM	Somalia Water and Land Information Management
UNDP	United Nations Development Programme
USGS	United States Geological Survey,
WMO	World Meteorological Organization

Glossary of terms

Deyr	October to November, minor wet season
Gu	April to June, major wet season
Hagaa	July to September, minor dry season
Jilal	December to March major dry season in Somalia
Togga	Anon perennial (seasonal) stream which deep and narrow
Waadi (Wadi)	A non-perennial (seasonal) stream which is wide and shallow

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Acknowledgement

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Executive Summary

Floods are the most prevalent form of natural disasters along the Juba and Shabelle Rivers in Southern Somalia, whereas flash floods are common occurrences along the intermittent streams in the northern part of the country. Both riverine and flash floods cause high numbers of casualties and economic impacts. As the population grows and urban development encroaches into traditional floodplain areas, in the riverine areas, and in the towns of Garowe and Hargeysa, the potential for loss of life and property will rise in the coming years. For example Hargeysa and Garowe cities in northern Somalia have grown rapidly due to high influx of immigrants resulted from the long civil war. Due to lack of legislations, many people have settled in floodplains risking their lives and introducing high vulnerability. Early warning and alert systems are not in place and if existed are rudimentary. Establishing flood early warning systems for the areas at risk of flooding is the most effective means to reduce the death toll caused by these floods.

One of the FAO SWALIM's mandates is support to the Somalia interagency efforts in developing information products and tools that will provide early warning information and aid preparedness and response to floods in Somalia. SWALIM has been providing supportive information and technical capacity to the interagency efforts for the past four years in collaboration with USGS and FEWSNET. This feasibility study was commissioned in line with these mandates with a main goal to improve flood forecasting and alert systems through assessment of existing capacities and lay out of technical options for the development of a river flood forecasting system for the Juba and Shabelle basins and flash flood alerts systems for Hargeysa and Garowe cities in Northern Somalia.

The report provides the basis for implementation of flood forecasting and flash flood alert systems for the above mentioned areas. As part of the preparation of this document, a number of documents that provided physical details of rivers and Wadis in Somalia were reviewed, assessment of the existing hydro-meteorological data collection network, and consultation with agencies and organizations that are active in flood response and relief within Somalia were carried out.

To put into effect a program to reduce the recurring losses in human lives and economic assets due to riverine flooding in the Juba and Shabelle Rivers, the following recommendations need to be implemented.

1. Establishment of automatic real-time hydrometeorological data collection, transmission and monitoring system

The network can be housed and operated by the same organizations that are operating the manually read hydrometric and meteorological stations that are in place at selectcted key stations. Routine maintenance of the equipment and data archiving can be done by a central organization such as SWALIM or SWALIM in partnership with the Kenya Meteorological Department (KMD). As part of this real-time hydro-meteorological data collection network, the following steps are considered essential:

i. Upgrading of some of the existing manually read hydrometric and rainfall recording stations (outlined in Figure 15) to automated stations.
ii. Implement a proper satellite-based data telemetry system that is capable of transmitting data in the worst conditions of flooding possible in the area.
iii. Implement training programmes for local personnel on equipment operation and maintenance for the hydro-meteorological measuring equipment.
iv. Establish an operational maintenance plan for the hardware components of the hydro-meteorological data collection and transmission network.
v. Establishment of a collaborative working relationship with KMD for the automatic weather stations equipment maintenance and data sharing.
vi. Start a process that will add the automated weather stations installed under this program into the WMO Global Telecommunication System (GTS). In that regard, approach as soon as possible the WMO.
vii. Institute hydrometric and weather data archiving and quality control procedures.
    a) For the archiving of the hydrometric data, we suggest that SWALIM continues to use the HYDATA database.
    b) For the archiving of the weather data, suitable software such as the FAO-supported AGRISOFT should be explored.

2. Establishment of an Operational Flood Forecasting Centre (FFC)

The main task of the FFC will be the issuance of daily and sometimes sub-daily (during the course of a flood event) flood forecast advisories and bulletins for forecast service sites. The forecast service points should be expanded to include new locations along the two rivers as more points with stage/discharge rating relationships are made. The FFC should include:

i. Hydrologic modelling capacity should be established at the FFC, and the personnel at the FFC should be capable of calibrating and adapting existing hydrologic models to the hydrologic and hydraulic conditions of the Juba and Shabelle rivers system. As a first phase of building the flood forecasting capabilities the following is recommended:
    a) A forecasting model based solely on routing could be used. We recommend the parametric wetness-index-based Linearly Varying Gain Factor Model (LVGFM), a module of the Galway Real-Time River Flow Forecasting System (GFFS), a freely available software package developed by the Department of Engineering Hydrology of the National University of Ireland, Galway.
    b) With time, we suggest that a semi-distributed physically based rainfall-runoff model (e.g., GeoSFM, version of the MIKE-SHE model), that could incorporate remotely sensed and observed rainfall, be used as a flood forecasting model; such a model should have a modelling domain that covers the whole Juba and Shabelle basins when implemented.

c) Develop a flood warning dissemination protocol. For the dissemination of the warnings on river floods, investigate what kinds of data and information needs the potential users of the system have. For now, we suggest that SWALIM practice of disseminating warnings through e-mail be continued, but that effort should be extended to contact media outlets that are widely listened to and watched in Somalia, e.g. BBC Somali Service.
d) Implement a program of sensitizing and educating the communities at risk of river floods on the meaning and actions required during and after a flood alert or warning is issued.

3. For major settlements along the two rivers (Belet Weyne, Bulo Burdi, Jowhar and, Afgoi along Shabelle, and Luuq, Bardera, Jilib and Jamame along the Juba), create possible floods inundation maps. Such maps, if linked to observe/forecasted river levels and superimpose on high resolution satellite imagery (e.g., QuickBird imagery), will provide information on the potential number of properties and people affected by a flood. Such maps will also be useful for public awareness and for flood relief work.
4. Acquire high resolution Digital Elevation Model (DEM) data that cover the floodplains of the Juba and Shabelle. Closer to major settlements, the survey area should be widened when acquiring the elevation data source.
5. Delineate floodplains from hydrologic modelling and satellite imagery based on the peak historic floods that every area of interest has experienced. Such maps will be of immense value for areas with authorities who can enact land use laws that are needed to restrict economic activities in the river and streams natural floodplains.
6. Implement a program of updating the pre-war river stage/discharge rating curves for all the forecast locations.
7. For all the proposed hydrometric station locations we propose that stage–discharge relationship be develop using hydraulic models that are based on the complete one-dimensional equations of the unsteady flow.

To implement flash flood alert systems for the towns of Garowe and Hargeysa, we recommend the items listed below.

1. Establish a network of automatic rain and stream gauges in the two basins supported by real time satellite rainfall estimates.
2. Create a series of probable rainfall intensity estimates for the Garowe wadi at Garowe town and Hargeysa wadi at Hargeysa town.
3. Carry out community-based preparedness and early warning programs in the region to raise community awareness and capacity to reduce vulnerability to extreme floods.
4. Map the floodplains extent of the two wadis.

1. INTRODUCTION
1.1 Problem Definition

Floods are the most widespread climate-related hazards in the world, and they impact more people globally than any other type of natural disaster (World Disasters Report, 2003). Historically, along the Juba and Shabelle Rivers (the area is known as the riverine area in Somalia), floods have been the most prevalent form of natural disaster. Lately, there has been a discernable increase in the severity and frequency of the floods in the areas along the Juba and Shabelle Rivers. The most recent severe flood events were the floods of the Deyr in 1961, 1977, 1997, and 2006, and floods of the Gu in 1981 and 2005. The last three major flooding events had magnitudes larger than the one associated with the historical 50-year return period flood event.

Even if the trend toward an increase in flood frequencies is questioned, it is certain that the economic damage and casualties that result from flooding in the area have increased with time. For example, the number of fatalities in Somalia attributed to the 1997/98 El Niño floods were the sixth highest total attributed to floods globally for the decade of the 1990s (Loster, 1999). The increase in both severity and damage (both economic and causalities) caused by floods, apart from the natural increase in frequency and severity mentioned already, is due to several other human made factors:

1. The encroachment of people upon traditional floodplains, as population increases and pressure on land increases, is leading to enlargement of the number of people dwelling in traditional floodplain areas. Predictably, as more people start living in floodplains, the potential for loss of life and property will rise.

2. The major flood relief channels that were maintained by the Somali government departments before the start of the civil war are in disrepair. Floods that are caused by the poor state of the flood relief canals occur mostly in the Lower and Middle Shabelle areas.

3. The deterioration of the river embankments and the unrestricted breaking of river embankments for irrigation purposes often lead to flooding during periods when the river levels are still below historical bank full stage.

To lessen the negative impact of the floods in Somalia, there is a need to commence a program that implements flood control measures. Flood control measures are normally both structural and non-structural. Some of the structural measures that are needed immediately in Somalia for areas along the Juba and Shabelle Rivers are (a) the repair and rehabilitation of the major flood relief and irrigation canals (some irrigation canals had a dual purpose of flood relief), and (b) the repair of the numerous breakages in the river embankment. The non-structural flood control measures needed are (a) the establishment at the national level of a Flood Forecasting Centre for the riverine areas and formation of community-based Flash Alert Centres and needed resources for the dry seasonal streams of the Northern regional states, and (b) the implementation of legislations and policies on land use that should restrict permissible economic activities in the floodplains.

The United Nations Development Program (UNDP) for Somalia is spearheading a program that aims to repair some of the major flood relief canals in the Shabelle River. In the past few months, they have rehabilitated and put into operational mode the Duduble canal on the Shabelle. According to the UNDP Engineer, experiences gained during the *Gu* season of 2007 will show if the repairs of the Duduble canals were done properly and if the canal has resumed to act as a safety valve for floods in the Middle and Lower Shabellle regions. The UNDP also has a team that is repairing breaches on the Shabelle embankment between Jowhar and Balad towns.

The centrepiece of a program that aims to control the negative effects of flood in Somalia should be the establishment of an operational flood forecasting/flash flood alerting capacity. It has been recognized throughout the world that flood early warning systems are the most effective means to reduce the death toll caused by floods. At this time in Somalia, there is neither a national river flood forecasting system nor a flash flood alert system capacity in place. In addition, the country lacks any institutional capacity in operating such systems or the real-time hydro-meteorological data collection and transmission network that is a crucial component for the success of any operational flood forecasting and warning system. To save lives and be effective, flood forecasting and flash flood alerting systems will need to be coupled with a proper warning dissemination system that has communication links with the flood-affected communities.

1.2 Purpose and Objectives

This report was commissioned by the Food and Agriculture Organization (FAO) Somalia Water and Land Management - SWALIM project that is funded by the European Commission (EC). The objective of this feasibility study is to provide the basis for the implementation of a flood forecasting system for areas along the Juba and Shabelle Rivers and a flash flood alert system for the towns of Hargeysa and Gorawe. In the future, and when the recommended flood forecasting system and flash flood alert system are implemented, it is expected that there will be a reduction in loss of lives that has been seen in the area in the past, and it is also expected that material damage caused by floods will be lessened because of the increased time for evacuation that the use of such system will make possible in the future.

As part of the preparation of this document a number of documents have been reviewed and provided physical details of rivers and structures on the rivers, historic data on previous floods in the study area, GIS data layers of the study area, and similar studies done around the globe. Most of the documents reviewed are stored in the SWALIM library. A list of some of the references that were reviewed is presented in the reference section of this report.

The main objective of this assessment was to carry out an analysis of existing capacities, needs, and technical options in the development of a river and flash flood early warning systems for parts of Somalia, and to make appropriate recommendations on the models and hardware required for the establishment of such a system. The river flood early warning system is intended for the Juba and Shabelle Rivers which frequently flood communities in the riverine areas, while the flash flood alert system will be for the tugs that cross the cities of Garowe and Hargeysa. The components of this assessment include:

- Requirements analysis for flood warning information needed by the entities responsible for preparedness, warning, and response;
- Assessment of the hydro-meteorological data collection and modelling capacities at SWALIM (the agency that now produces flood early warning for any part of Somalia);
- consultation with agencies and organizations, besides SWALIM, that are active in flood response and monitoring within Somalia;
- Preparation of a diagnostic report to SWALIM laying out technical recommendations and indicative designs and costs for a system to be considered for implementation.

2. GENERAL CHARACTERISTICS OF THE JUBA AND SHABELLE RIVER BASINS

2.1 Physical Characteristics

The Juba and Shebelle Rivers originate in the eastern Ethiopian Highlands, where the main streams and their tributaries are deeply incised on the steep slopes of the upper sections (see figure 2.1). The sections of the Shabelle River in Somalia receive no major tributaries. There is some local runoff from wadis during periods of local heavy rainfall; the most significant of those wadis are in the upper Hiiraan region. The Juba has two major tributaries, the Shabelle River and the Lag Dere. Inside Somalia, both tributaries join the Juba close to the river estuary in the Lower Juba. Most years, runoff contribution from the two tributaries into the Juba is zero.

The altitude of the Juba and Shabelle basins ranges from just above sea level in terminal areas to well over 3,000 above mean sea level (amsl) in the Ethiopian Highlands where they originate. In the headwaters of the Juba and Shebelle, rainfall is generally high and evapotranspiration relatively low, with a high runoff coefficient. The runoff coefficient is high because of the large areas of exposed rock that cover a large part of the headwater basins of the two rivers.

The area of the Juba basin is 223,000 km^2 when we exclude the Lag Dere and Shabelle sub-basin areas, with 166,000 km^2 of the above area located above Luuq. The Juba River is formed at the border of Somalia by the joining of three tributaries (Webi Gestro, the Genale, and the Dawa) just before the river enters Somalia at Dolow. The Gestro and the Genale tributaries form the Juba River just north of Dolow in Ethiopia, where the Dawa having formed the Kenya-Ethiopia border and the Somalia-Ethiopia border in the area west of Dolow joins the Juba River at Dolow. The total length of the Juba River is about 1,100 km (measured on the longest tributary); half lies in Ethiopia and half lies in Somalia.

Figure 2.1: **Drainage Pattern of the Juba and Shabelle Rivers**

The Lag Dere sub-basin of the Juba is made up of a series of seasonal rivers that originate in Kenya. Basin elevation ranges from close to sea level to above 4,000 m in the Mount Kenya parts of the basin. Basin area is 253,000 km^2 with 75% of its area in Kenya. The annual floods of the Lag Dere often empty into the Dhescheeg Waamo, an area of depression that extends from close to the town of Afmadow to the Juba River. The upper part of the Lag Der basin is formed by the Ewaso N'giro River. The water of Ewaso N'giro empties most of the year in the Lorrian Swaps; the Ewaso N'giro River is an intermittent stream even before reaching the swamps. Water from the Lag Dere reaches the Juba River only in years of exceptional rainfall.

The Shebelle enters Somalia at Ferfer and runs south until it reaches the town of Balad; from there, it runs southwest, parallel to the coast. The river empties into a swamp before Haway. After Haway the river resumes a defined channel and the flows are generated locally. The river does not normally reach the Juba but ends in a depression area, where it is finally lost in the sand dunes that run along the length of the Indian Ocean in southern Somalia. Only with exceptionally heavy rains does water from the Shebelle River reach the Juba River. The total length of the Shebelle River is about 1,700 km, with about half lying in each country. The Shebelle basin area is around 307,000 km^2, with 199,000 km^2 in Ethiopia and 108,000 km^2 in Somalia. In Ethiopia, the main tributary of the Shabelle is the Fafan Tug with an area of 40,000 km^2. The Fafan Tug drainage area is the semi-arid Ogaden region. Runoff contribution from the Fafan usually reaches the Shebelle only in above average rainfall years. The Shebelle riverbanks generally lie above the level of the surrounding land downstream of Afgoi, with the consequence that bank full spillages into the floodplains are lost permanently from the river and little return flow into the river occurs.

The Juba River mean annual runoff at Luuq is estimated at 6,400 million m^3, with the Ethiopian part of the catchment contributing over 90% of the total volume (Kammer, 1989). Runoff contribution in the parts of the Juba basins in Somalia is small because of the low rainfall in this area. The mean annual runoff of the Shabelle River at Belet-Weyne is 2,384 million m^3, Kammer (1989). Although the Shabelle has a larger catchment area than the Juba, the flow in the Juba is about three times larger, partly due to higher average annual rainfall and due to the nature of the geologic formations underlying the two rivers. Whereas the upstream tributaries of the Juba lie over impervious basement rock and tertiary volcanic formations with low infiltration capacity; the formation underlying the upper Shabelle is mainly relatively soft permeable sedimentary rock, Kammer (1989).

In both the Juba and the Shabelle Rivers, flood waves travel slowly downstream, with flood travel time between the utmost upstream and downstream sections of rivers being on the order of several weeks. Both rivers exhibit significant flow attenuation. Figure 2.2 shows that the flow attenuation is more marked in the Shebelle hydrograph than the Juba. Flood waves seen in the two rivers are often generated from runoff that orginated in the areas of the two catchments that are in the Ethiopian highlands.

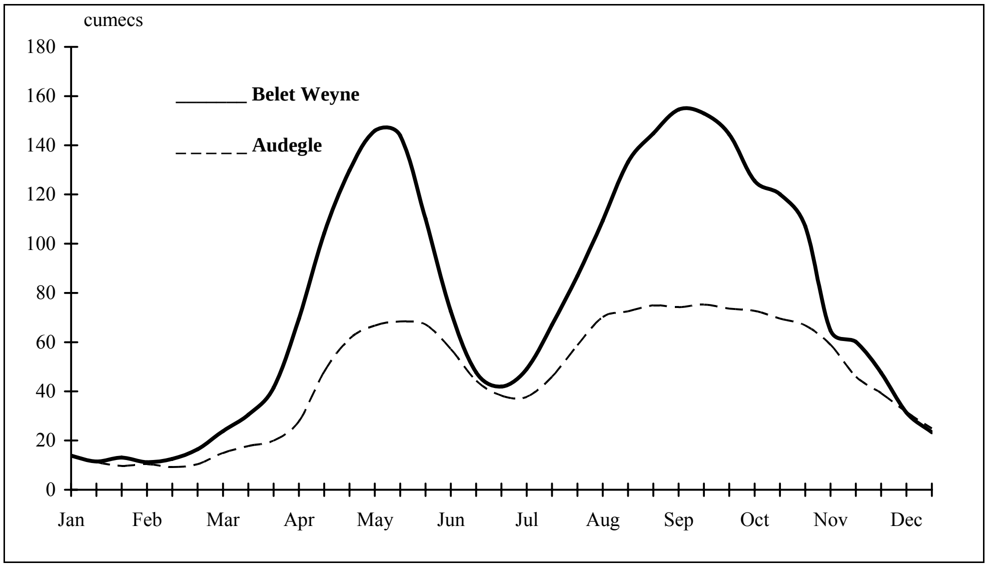

Figure 2.2a: Stream flow at upstream and downstream stations with recorded data on the Shebelle River in Somalia.

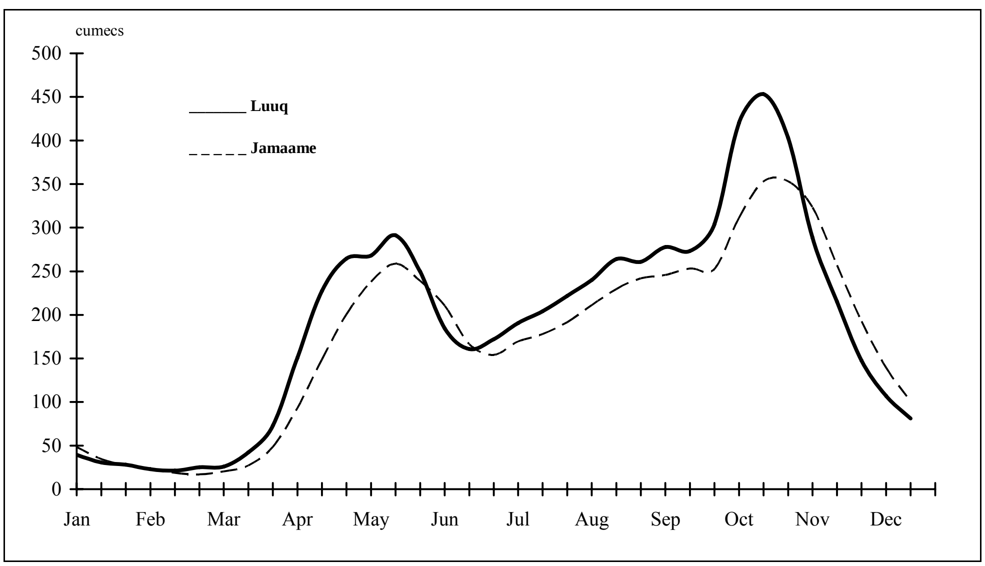

Figure 2.2b: Stream flow at upstream and downstream stations with recorded data on the Juba River in Somalia.

Table 1: Juba and Shabelle river reaches characteristic data, based on 1963 to 1990 observed data

Juba										
Station	Altitude (m)	Max. Width	Max. Depth*	Max. Flow	Reach	Length (km)		Avgerage	Avg. Wave	Avg. lag
	(amsl)	(m)	(m)	(cumecs)		Direct	Along Bed	Slope	(m/s)	(days)
Luuq (LG)	143	140	9	1,800						
					LG - BA	165	234	0.00023	1.2	2.3
Bardheere (BA)	90	100	8	1,800						
					BA - MA	217	412	0.00019	1.2	4.1
Mareere (MA)	13	85		590						
					MA - KM	20	39	0.00011	1.1	0.4
Kamsuma (KM)	9	85	8	507						
					KM - JA	28	53	0.00014	1.0	0.6
Jamamme (JA)	1	65	8	480						
Shabelle										
Station	Altitude (m)	Max. Width	Max. Depth	Max. Flow	Reach	Length (km)		Avgerage	Avg. Wave	Avg. lag
	(amsl)	(m)	(m)	(cumecs)		Direct	Along Bed	Slope	(m/s)	(days)
Belet Weyne (BW)	176	44	7	500						
					BW - BB	107	171	0.00024	1.0	2.0
Bulo Burti (BB)	134	48	8	440						
					BB - MW	98	188	0.00016	0.9	2.4
Mahaddey Weyne (MW)	105	46	5	166						
					MW - AF	111	199	0.00014	0.8	2.9
Afgoi (AF)	77	40	5	97						
					AF - AU	35	66	0.00011	0.6	1.2
Audegle (AU)	70.1	38	5	94						

Downstream of the Somalia-Ethiopia border, discharges reduce progressively in both rivers due to the lack of any significant flow contribution inside Somalia and because of natural losses (evaporation and infiltration) and water drawn for irrigation use. During flood times, there are water losses along the rivers that are due to overbank spillage into flood plains (Kammer, 1989). The rivers' characteristics are summarized in Table 1. Unlike rivers in humid parts of the world, where river discharge increases as the river goes downstream, the carrying capacity of the Juba and Shabelle Rivers decreases in the downstream direction. The only exception is found in Juba for the reach between Bardere and Luuq where, due to significant local runoff, the river's carrying capacity increases. In years of extraordinarily high rainfall in Somalia, there could a substantial runoff contribution from tributaries (e.g., 1997/98 and 2006), and those are the catastrophic flood years.

2.2 Climatic Conditions of the Juba and Shabelle Basins

Rainfall in the Juba and Shabelle basins is low and erratic with a bimodal annual pattern.The average annual rainfall for the Juba and Shabelle basins are 550 mm and 455 mm respectively. Rainfall in both basins varies considerably from the headwaters to the terminal sections. In the Juba basin, rainfall ranges from over 1,500 mm per year in the mountains, to 500 mm per year at its lower end in the south, to 200 mm per year on the Ethiopia-Somalia border. In the Shabelle basin, rainfall ranges from over 1,000 mm per year in the mountains, to 500 mm per year at its lower end in the south, to 200 mm per year on the Ethiopia-Somalia border. Interannual variability can be more than 300% of the long-term average rainfall.

Both rivers have two flood seasons, the Gu and the Deyr, reflecting the area rainfall patterns (see Figures 2.3 and 2.4). The two rainy seasons are related to the northwards and southwards passage of the Inter-Tropical Convergence Zone (ITCZ) over the Ethiopian Highlands. The Gu season runs from April to June, and the Deyr season runs from September to December. The Gu season is the major rainy season with more than 50% of the annual rainfall. It can also be seen that although 25-30% of the rain falls in the Deyr season in inland areas of the basins, the southern areas near the coast (e.g. Kismayo, see Figure 2.3) do not receive much rain in this season.

The Juba and Shabelle River flows are highly variable from year to year, reflecting the great spatial and temporal variability in climate. The annual flow variation of the two rivers could be as much as two and half times the long-term mean annual flow, as shown in Figure 2.4. The general pattern of river flow is similar on the two rivers.

In their lower sections, both rivers have a propensity to flood every five years (see Figure 2.5). Flooding takes place more often in the Deyr season than in the Gu season. The peak flows are sustained more in the Shabelle during the Deyr season than in the Juba. The Shabelle remains at bank full state or above for about 90 days in every five-year period, on average, where the Juba is estimated to reach or surpass bank full stage only about 30 days in the same period of time. Based on averages at Audegle, the Shabelle water levels nearly reach the flood stage level at a rate that implies mean flood frequency in the areas has a 2.33-year return period.

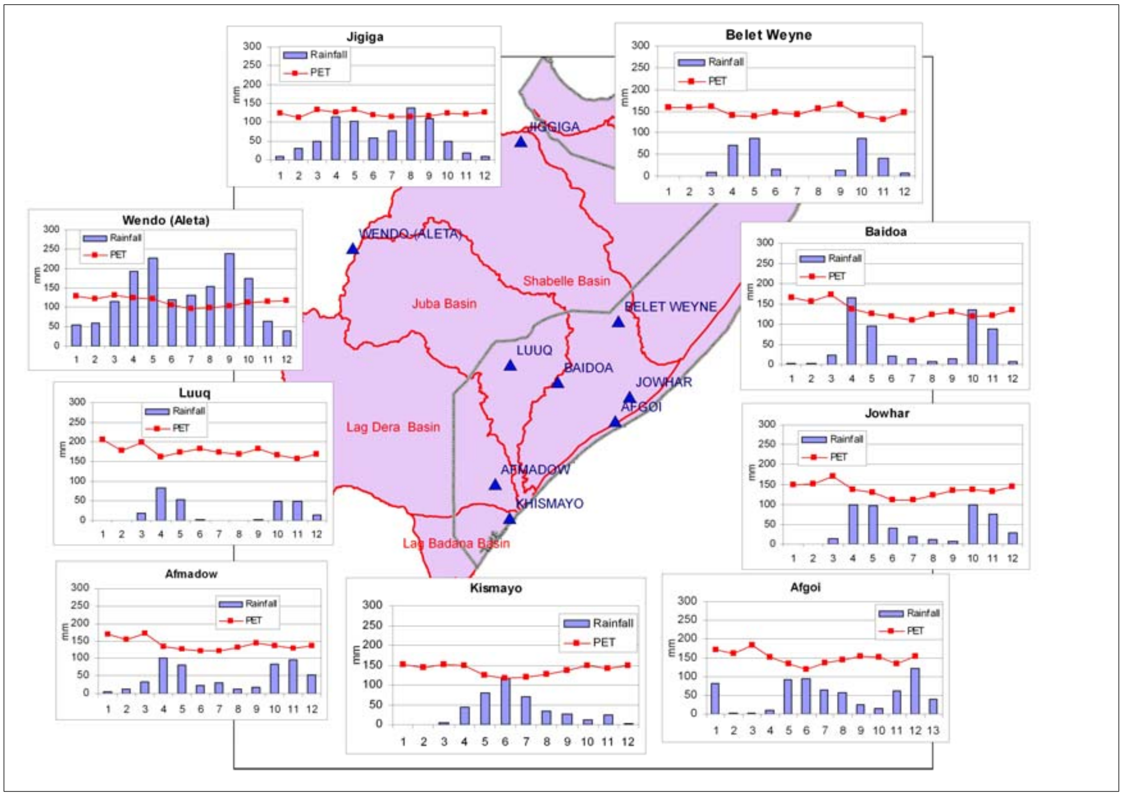

Figure 2.3: Mean Monthly Rainfall and Evapotraspiration Variation for Selected Stations in the Two Basins

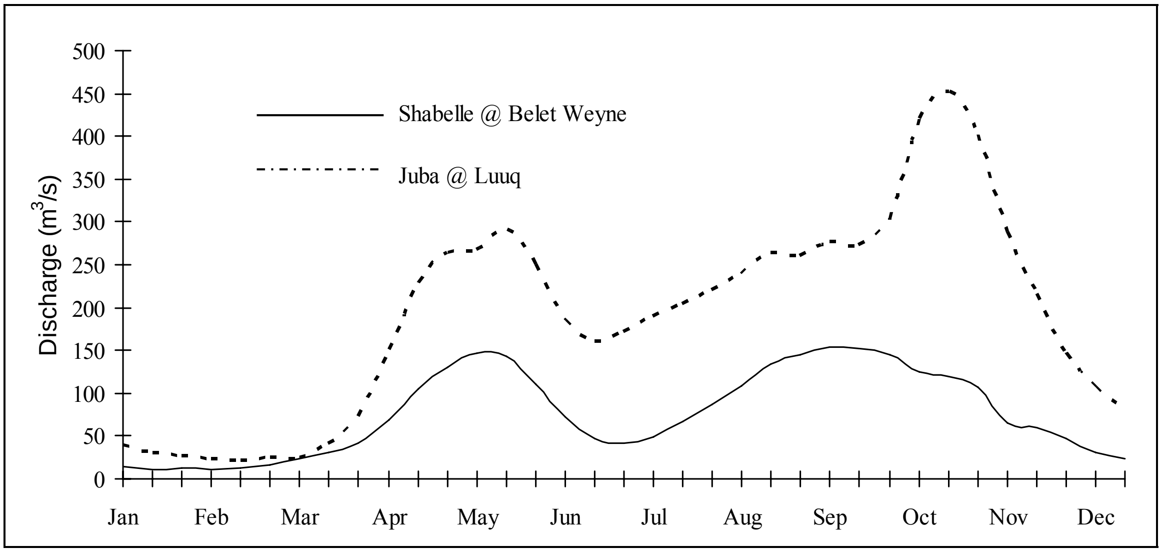

Figure 2.4: Long-term monthly average flows of the Juba and Shebelle Rivers at Luuq and Belet Weyne

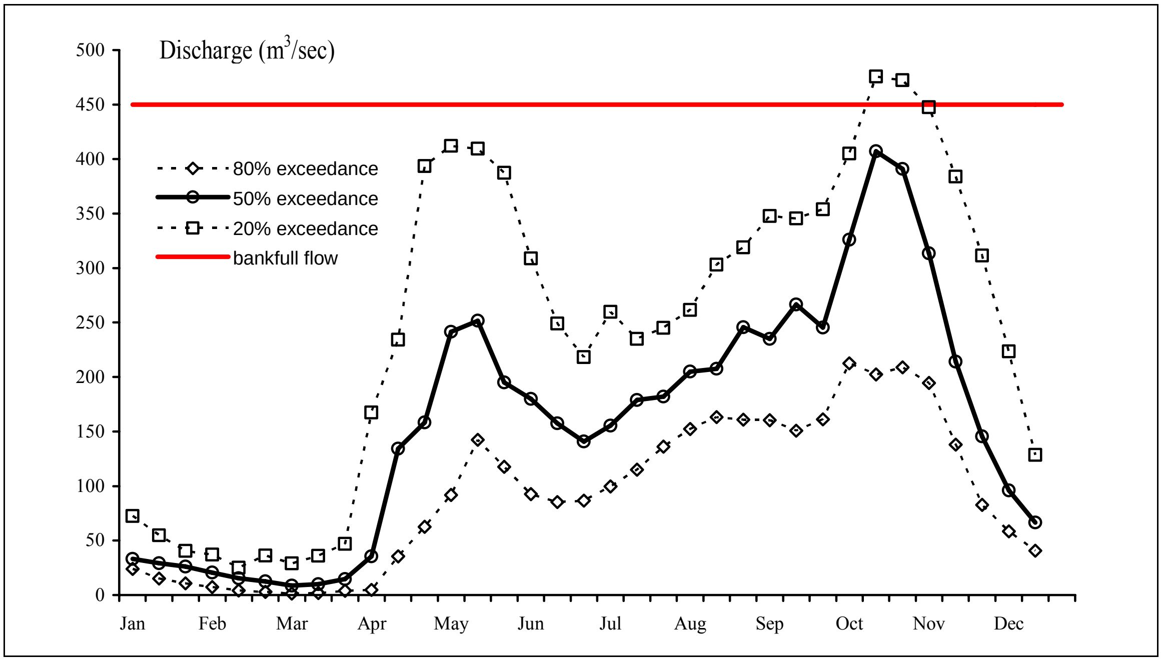

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Figure 2.5a: Exceedance flows and river bank full discharge at Jamaame on the Juba River

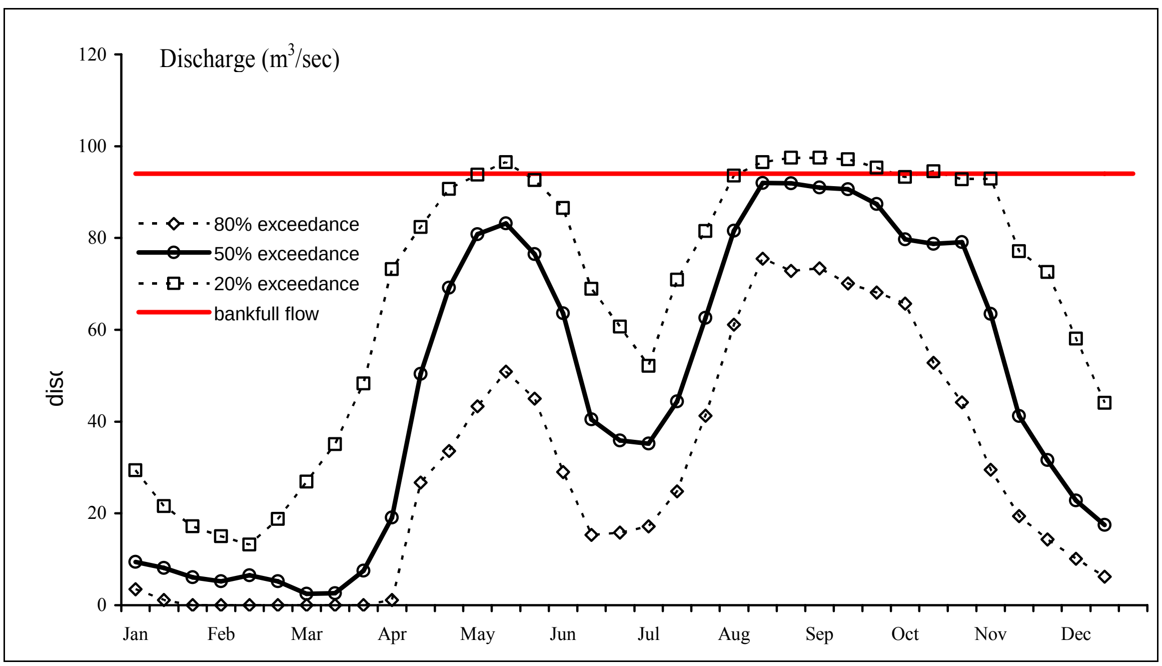

Figure 2.5b: Exceedance flows and river bank-full discharge at Audegle on the Shabelle River

2.3 Soil and Land Cover Characteristics of Juba and Shabelle Basins

The main soil types present on the hillslopes and plains of the Somali portion of the river basin are Eutric Vertisols, (deep clayey soils with >30% of clay that expand upon wetting and shrink upon drying), Haplic Calcisols (typical soils with accumulation of secondary carbonates in a calcic horizon), Haplic Solonetz, Lithic Leptosols (very shallow soils limited by hard rock to a maximum depth of 25 cm), Petric Gypsisols (soils with substantial secondary accumulation of gypsum (CaS04,2H2O), and in this case the gypsum is strongly cemented or indurate). In between the two rivers, a large outcrop of crystalline rocks belonging to the African basement is formed by granite, marble, quartzite, gneiss, and paragneiss (so-called Bur region). The basin soil properties suggest a high ratio of the rainfall becoming runoff during periods of relatively higher than normal rainfall in the area. The land cover of the floodplains and the alluvial plain of the two rivers in their Somali tract is covered by 66% wooded vegetation (mainly open shrubs), 18% rangeland (mainly closed to open savannah), 15% agriculture (mainly rainfed agriculture) and 1% other types of cover.

2.4 Major Infrastructure on the Juba and Shabelle

This section describes the major human made structures on the Juba and Shabelle Rivers and that could have an effect on the magnitude and timing of river flows. All the structures described here are barrages and primary canals. There are no dams on either river within Somali territories. Most of the structures are located on the Shabelle River. On the Juba, the flow-altering structure is the Fanoole dam. The Mott MacDonald (1996) and SWALIM (2007) Technical Report N^o W05, reports contain exhaustive information on the structures on the two rivers.

On the Shabelle, the first major barrage is the Sabuun barrage in the Middle Shabelle region upstream of Jowhar town. The barrage feeds the Duduble flood relief canal and the Jowhar Offstream Storage Reservoir (JOSR). The Duduble canal is the only canal built solely for flood relief. The first study on the flood relief channel at Duduble (also known as the Chinese Canal) was initiated in 1969, and a detailed study for implementation of the canal was completed in 1983. The canal is intended as a flood relief canal for the flood-prone areas along the Shabelle River in the Middle and Lower Shabelle regions. The canal diverts 40 m^3/s of the flood water into a natural spillage area, 40 Km north of Jowhar town, which was proposed as the Duduble Reservoir. The canal has been falling into disrepair since the civil war period due to high silting of the canal bed and malfunctioning of the canal intake gates. According to UNDP, on average, about 20 cm of silt builds up in the channels after every flood season (Hussein Nur, personal communication). The UNDP has rehabilitated to an extent the Duduble canal, and the canal was declared operational starting from the Gu season of 2007.

Another major canal served by the Sabuun barrage is the FAO canal that diverts water into the JOSR reservoir. The reservoir was commissioned primarily to collect surplus river flow during the wet season and to release stored water during the dry season for irrigation. The JOSR supply channel located about 20 Km north of Jowhar is also used as a flood relief channel. The reservoir intake canal has a design capacity of 50 m^3/s and the reservoir has a design capacity of 200 million m^3 and covers an area of approximately 100 Km^2. The reservoir was designed to use a natural depression on the left bank of the river. According to Sir M Mc Donald and Partners Ltd (1984), the reservoir outlet canal had a design capacity of 25 m^3/s. The JOSR structure and related canals have not been in operational status since the start of the civil war in 1991. Any flood forecasting system implemented for the Shabelle downstream of Jowhar should include the modifying effects of the FAO and Duduble canals on the magnitude of stream flow.

Another major infrastructure on the Shabelle rive is the Janaale barrage which is located in the Merka District. The barrage has a dual purpose of diverting water for irrigation and acting for flood relief. The Janaale barrage regulates the river level at Janaale and diverts water in Cessare Maria and Primo Primario canals on the left bank of the river and on Asayle canal on the right bank of the river. The barrage was also used as flood relief. The barrage diverted water through the Cessare Maria canal to spill in areas of the dunes near Sinay; water diverted through the Primo Secondario went to the Gofca channel, created from the remains of a previous course of the Shabelle River (Sir M Mc Donald and Partners Ltd, 1978).

The Qoryooley barrage is located approximately 26.3 km downstream of the Janaale barrage. The barrage diverts water primarily into the Fornari (aka Wadajir) and Liban canals. There are also close to 20 small canals that benefit from barrage river level rise. The barrage has a design river water level of 67.16m amsl. The barrage at present is poorly functional. There are another four barrages downstream Janaale including Qoryoole built for irrigation and flood control purposes. These are Mashalaye, Falkeero and Kurtunwary.

The Fanoole dam is the only dam located on the Juba River, north of Jilib town in the Middle Juba Region. The barrage was designed to divert 33.4 m^3/s of water for irrigation purposes. Fanoole has not been in operation since the beginning of the civil war in Somalia in 1991.

2.5 History of Floods along the Juba and Shabelle

The low-lying areas along the Juba and Shabelle Rivers have experienced flooding of various magnitudes in the past few decades. In the time periods that we have observed stream flow data (1961–1990 and 2002–2006), there were six severe flooding events along the Juba and Shabelle Rivers. The major floods took place in the Deyr of 1961, Deyr of 1977, Gu of 1981, Deyr of 1997, Gu of 2005, and the last one during the Deyr of 2006. Figure 2.6 depicts the flows of the Juba at Luuq and the Shabelle at Belet Weyne respectively during these flooding events. Although there is lack of observed flow data between 1990 and 2002, the El Niño rains of 1997/1998 caused severe floods in a large section of all areas along the Juba and Shabelle Rivers. The floods of 1997/98 were the worst seen in the riverine areas in living memory.

Usually, major floods that affect most of the riverine areas are due to heavy rainfall over the Ethiopian highlands. During the floods of 1997/1998, exceptional rain amounts were received throughout the two basins. All the settlements along the Juba River in Somalia were flooded, with some villages cut off completely by the water for extended periods of time. For the Shabelle, many villages along the river were under water for a prolonged period. Hundreds of thousands of people were left homeless with the floods affecting negatively the lives of up to 1 million people. The 1997/1998 floods were estimated to have caused about 2,000 deaths and displacement of about one million persons. These floods led to the collapse of virtually all the large irrigation schemes and damaged all major flood relief channels, roads and other major infrastructures.

Before the 1997/1998 floods, the worst floods to hit the areas along the upper Shabelle in Somalia were the 1981 Gu floods; along the Juba, the floods of the Deyr of 1977 were the worst. The floods of the Gu in 1981 were the largest floods on record (up to that time) in the Middle Shabelle and the second highest recorded in the upper and middle Juba (Gemmel, 1981). It was estimated that a large proportion of the flood water during the 1997/1998 floods came from runoff generated within Somalia.

The next largest floods were the floods of the Gu season of 2005. During this season, flooding took place in many riverine areas despite that rainfall in southern Somalia for the season was average and below average. The 2005 Gu season floods were mainly due to the heavy rains that had fallen in the Ethiopian highlands on the headwater watersheds of the two basins. SWALIM-recorded river gauge data for the Shabelle Rivers at Belet-Weyne and the Juba River at Luuq indicated that the floods were more severe along the Shabelle than the Juba. Recorded flows of both rivers went over the historical 30-year return period flows. The peak flows of the Shabelle, although of similar magnitude to the flows that were seen during the floods of 1981, were sustained for a far longer period.

During the Deyr season of 2006 (October-December), torrential rains that fell in Ethiopia, Kenya, and Somalia led to large scale flooding in many locations along the Juba and Shabelle Rivers in Somalia. In some areas of the two basins, recorded rainfall during the Deyr season of 2006 was estimated to have been more than 200 to 300 percent above the normal rainfall of the area. It was reported in early November of 2006 that the stage of the Shabelle River at Belet Weyne surpassed the mark of the flood stage associated with river flows of the 50-year return period. The river submerged the main bridge of the town, and most of Belet Weyne was under water for several days. For the Juba River, it was estimated that the stage at Luuq reached the 20-year return period flood stage. In early November 2006, it was estimated (CAP, 2006) that 350,000 people living along the rivers were displaced, inundated, or otherwise seriously affected by the floods with the possibility of up to 90,000 people being displaced before the end of the Deyr season.

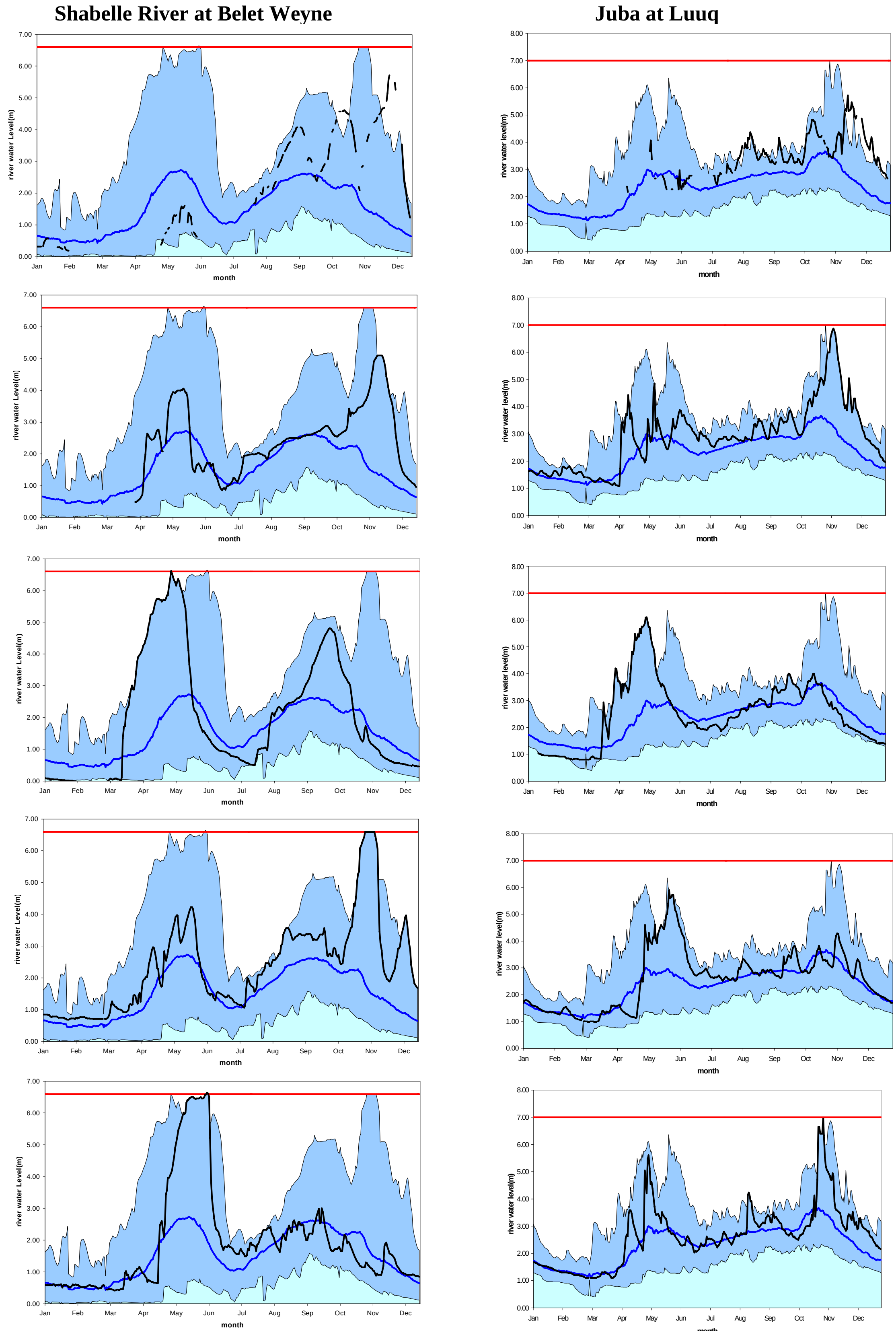

Figure 2.6: **Flows of the Juba and the Shabelle during the flooding events**

2.6 Trans-boundary Issues

Although 90% of the water of the Juba and Shabelle Rivers originated from Ethiopia, there is now no transboundary hydro-meteorological data sharing between the two countries. The stream flow data from a real-time observing system on the Juba and Shabelle Rivers and tributaries in Ethiopia will be extremely beneficial to flood forecasting activity for the areas along the Juba and Shebelle Rivers in Somalia. For example, an automated stream gauge station on the Shabelle at Godey will increase flood-warning lead-time by about two or three days for all the forecast locations on the Shabelle Rivers that are located in Somalia.

The Ethiopian Ministry of Water Resources (EMWR) operates a network of stream gauges along the Shabelle River and on tributaries of the Juba on the Ethiopian side of the two rivers (see Figure 2.7). An effort should be made to establish cooperation with the EMWR on stream flow data sharing. Helping the EMWR to establish real-time telemetric stream gauge stations could be the way to foster such cooperation. Another point of cooperation with the EMWR will be sharing information on the timing of water releases for dams upstream on the two rivers if such dams exist.

We do not know of any significant dam structure in Ethiopia that could alter the flood wave characteristics on either the Juba or Shabelle River systems, but we recommend that a reconnaissance-level investigation be carried out on the possible effects of barrages and dam structures on the Ethiopian side on flow characteristics of the two rivers.

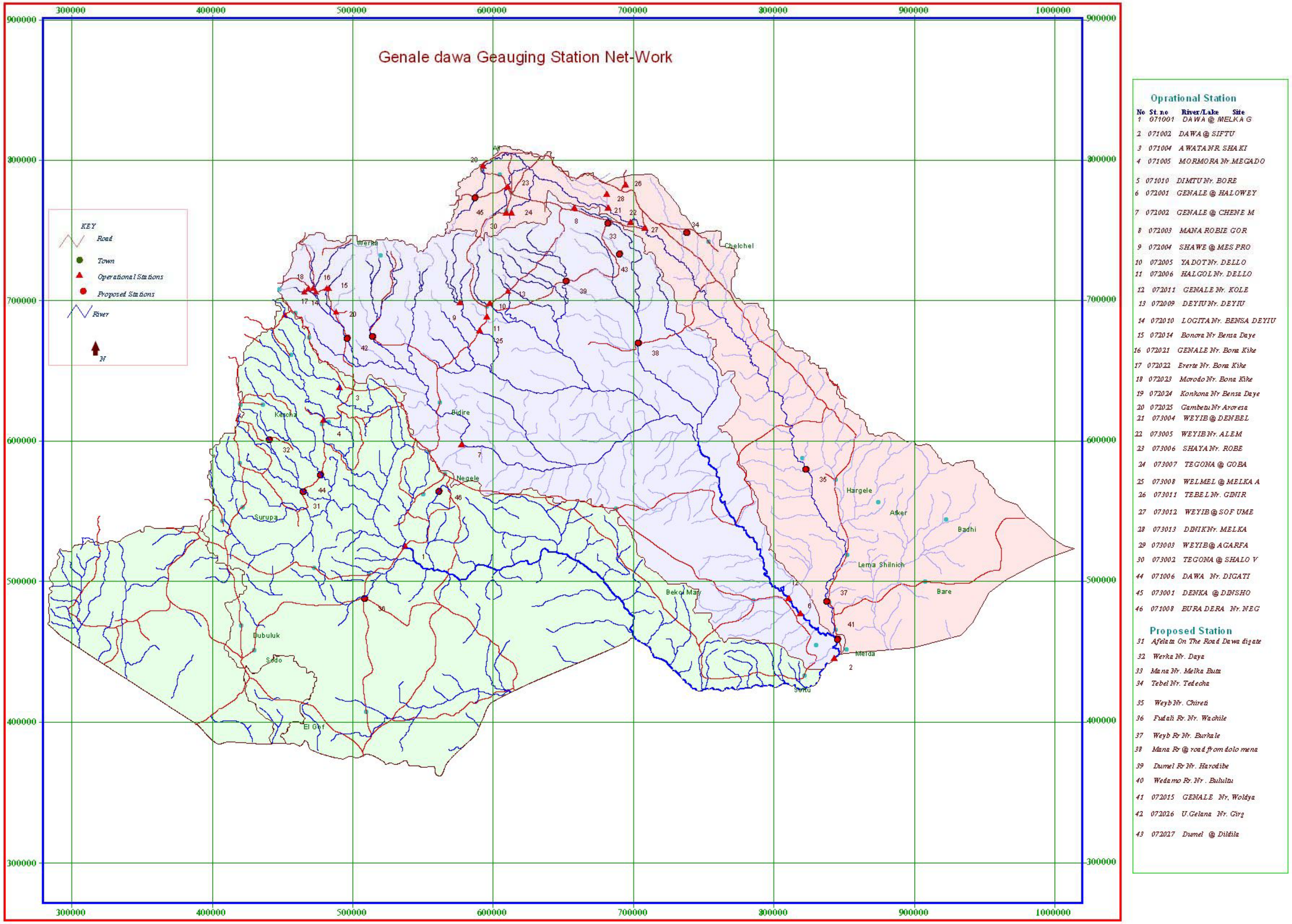

Figure 2.7a: Gauging stations along the tributaries of the Juba River in Ethiopia.

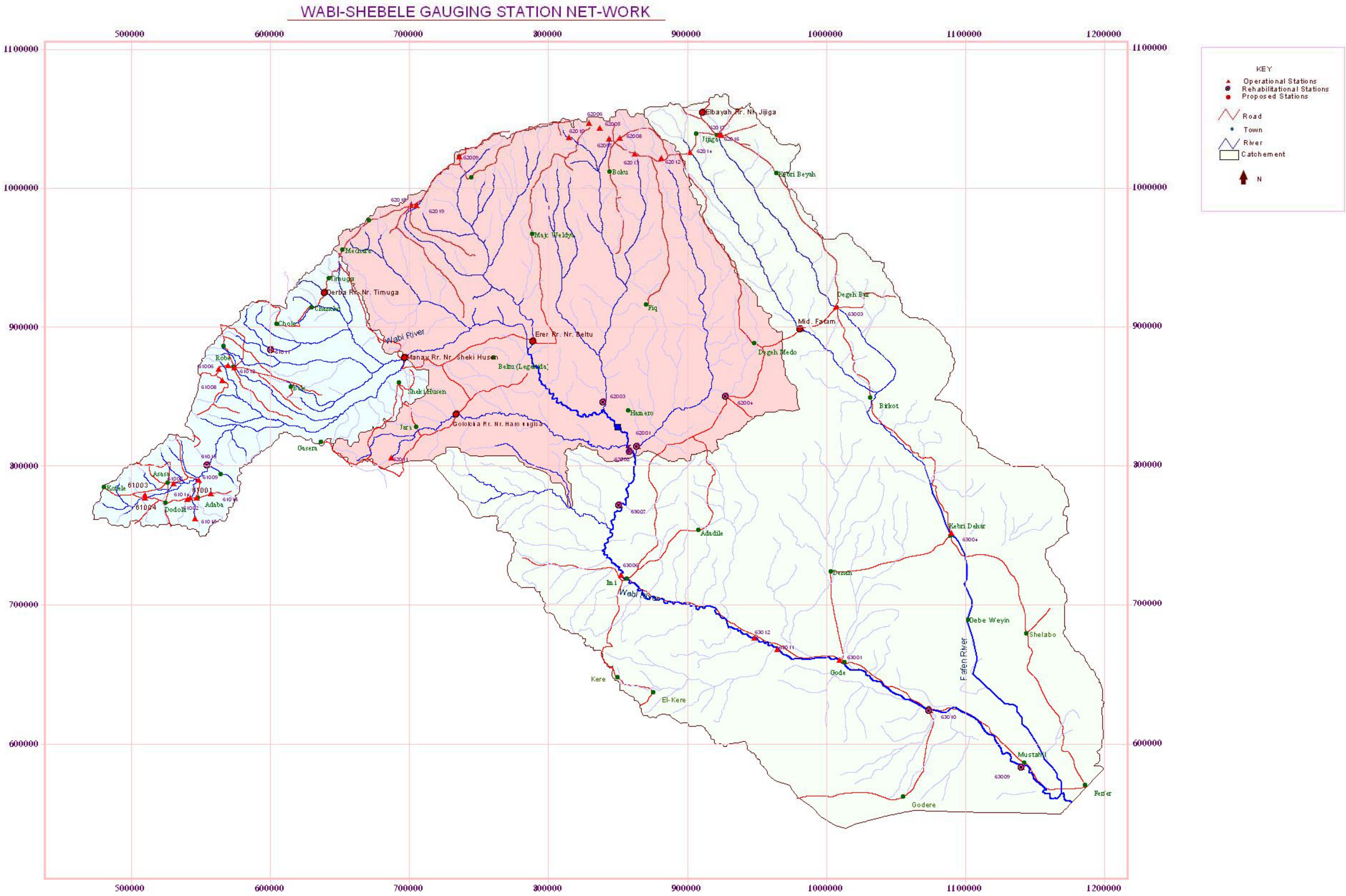

Figure 2.7b: Gauging stations along mainstream Shabelle River and tributaries in Ethiopia.

3. REVIEW OF CURRENT FLOOD MONITORING CAPACITIES

3.1 Databases & Information Management Systems

Figure 3.1 shows the location of the historical river gauging sites on the Juba and Shabelle Rivers.

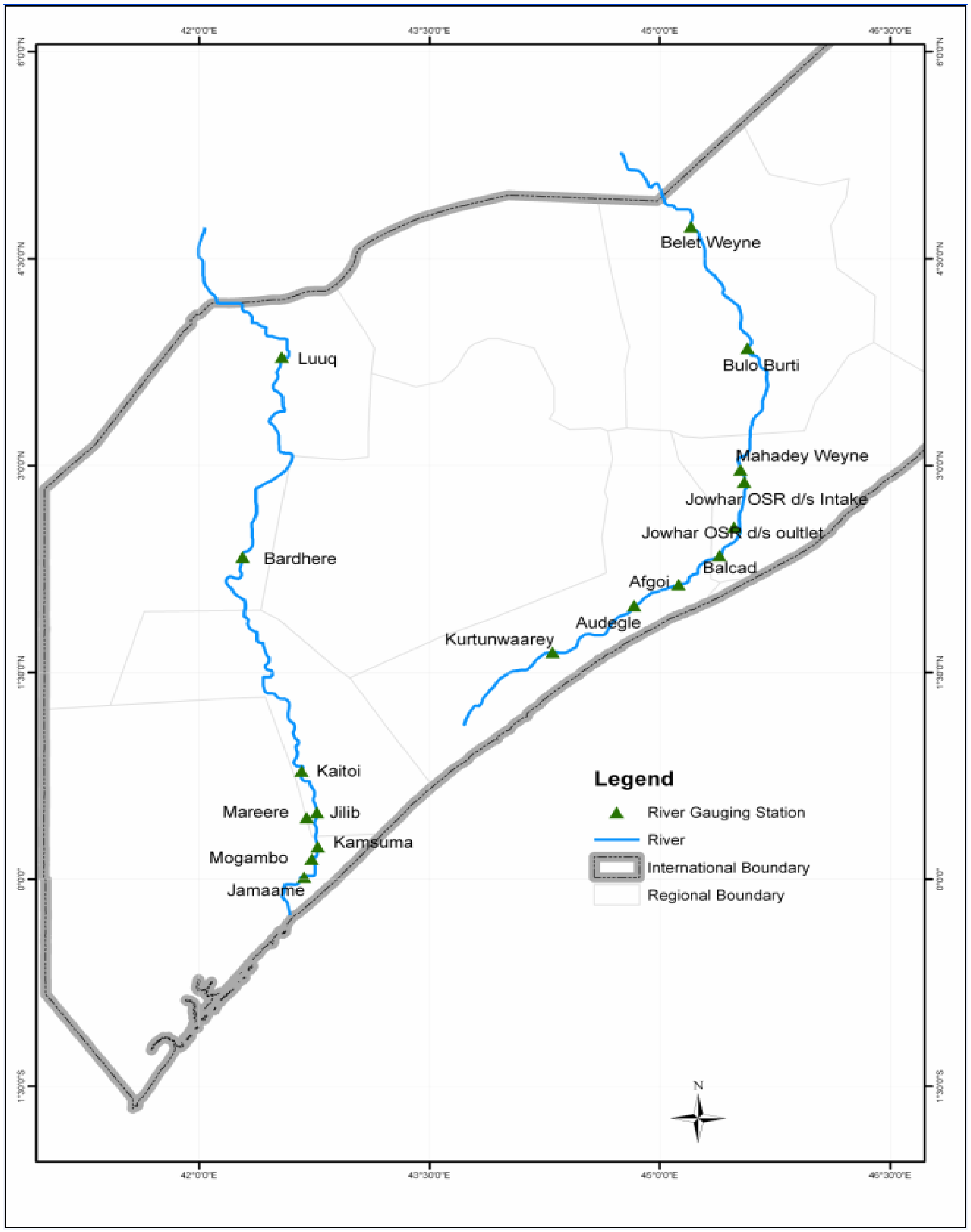

Figure 3.1: Historical gauging sites on the Juba and Shabelle Rivers.

The two oldest hydrometric stations are the uppermost stations of Luuq and Belet Weyne. Records of water level readings for the two stations go as far back as 1951. Although these early records include many gaps, the data are available in the Somalia Climate Archive databases maintained by SWALIM (for time series data the HYDATA is used). The network of gauging stations downstream of Luuq and Belet Weyne was established as part of an FAO-funded study in 1963. The gauging network deteriorated over the subsequent 20 years until the 1980s when a project led by MacDonald/IH rehabilitated most of the stations. Due to the civil war in the 1990s, the hydrometric network fell into complete disrepair with no monitoring or collection of water level data in either of the two rivers within Somali territories. Table 2 summarizes the archived hydrometric data for the Juba and Shabelle Rivers. The SWALIM HYDATA database contains the parameters of the rating equations for all of the stations. Such rating curves would need to be updated before using them to transform water levels to discharge amount. In the next few sections, we will describe the existing hydro-meteorological data collection network and other needed flood forecasting and monitoring capabilities and resources.

3.2 Operational Hydro-meteorological Network

After the outbreak of the civil war in Somalia, all of the hydrometric and weather stations that were operated by the Ministry of Agriculture (MoA) fell into disrepair or were looted. SWALIM started rehabilitating the hydrometric network in 2002; to date, six stations have been reinstated. The six hydrometric stations that are functional, albeit at different levels of data reliability and latency, are the gauges at Luuq, Bardhere, and Buaale on the Juba River, and Belet Weyne, Bulo Burti, and Jowhar on the Shabelle River (see Figure 3.1). The gauges at Luuq, Belet Weyne, and Bulo Berdi were rehabilitated by the SWALIM project. The gauge at Jowhar gauge was established and is maintained by the NGO Comitato Europeo per la Formazione e l'Agricoltura (CEFA), an Italian NGO that is active in the area of best agricultural practice training. The river gauges at Bardhere and Buale were established by CARE and World Vision International (WVI), respectively.

The staff gauges that were rehabilitated by SWALIM were installed from March 22 to April 4, 2002. An effort was made to fix the new staff gauges at the same level datum of the gauges that were maintained before the war by the hydrometric project of the Ministry of Agriculture. After installation, it was discovered that the gauge at Belet Weyne had discrepancy with the pre-war gauge datum (CEFA Final Report, 2002). An adjustment has been made to readings to take into account the discrepancy. The gauges at Luuq and Belet Weyne are composed of two staff plates, and the gauge at Bulo-Burti is made up of three plates. The combination of plates is made necessary by the wide variation of the river levels. Another six gauges (3 in each river) are planned for rehabilitation by SWALIM during this phase of the SWALIM project.

The staff gauge at Luuq was installed on the left bank of the river on the downstream side on the bridge. The gauges rate from 0 m to 7.5 m level. The first plate goes from 0 m to 5 m and is set on the second pillar of the bridge; the second plate measures river levels from 5 m to 7.5 m and the gauge is fixed on the first pillar of the bridge. The gauge at

Belet Weyne is situated on the right bank of the river, attached to the downstream side of the bridge. The gauge plates measure river levels from 1.7 m to 6.3 m.

Table 2: Locations and metadata for the archived stream flow data for the Juba and Shabelle Rivers[2]

Site ID	Station Name	Time Series	Area Km^2	Lat.	Lon.	Elevation (m)	Start Date	End Date	Missing data	Data Source
Juba										
1	Luuq	Daily flow	166000	03:47:29	42:32:30	141.4	1951	To date	1968,1991-2000	IH, Care Somalia
2	Bardheere	Daily flow	216730	02:20:30	42:17:00	89	1963	To date	1968,1990-2000	IH, Care Somalia
3	Jamame	Daily Flow	268800	00:01:10	42:41:00		1963	1990	1968	IH
4	Kaitoi	Daily Flow	240000	00:47;30	42:40:00	25	1963	1990	1965 - 1971	IH
5	Mareere	Daily Flow	240000	00:27:00	42:42:00	10	1977	1990		IH
6	Kamsuma	Daily Flow	255000	00:14:40	42:46:30		1972	1989	1977-1987	IH
7	Mogambo	Daily Flow	260000	00:09:00	42:44:00	14	1983	1989		
Shabelle										
10	Belet Weyne	Daily Flow	207000	04:44	45:12:20	176.1	1951	To date	1953, 1991-2001	IH, SC (UK-Somalia)
11	Bulo Burti	Daily Flow	231000	03:51:20	45;34:20	133.4	1963	To date	1991-2001	IH,CINS
12	Mahadey Weyne	Daily Flow	255300	02:58:20	45:31:50	104.6	1963	1990		IH
13	Balcad	Daily Flow	272700	02:21:00	45:23:30	95	1963	1979		IH
14	Afgoi	Daily Flow	278000	02:08:40	45:07:30	77.4	1963	1990		IH
15	audegle	Daily Flow	280000	01:59:10	44:50:00	70	1963	1990		IH
16	Kurtunwaarey	Daily Flow		01:39:00	44:18:00					IH
26	Jowhar	Water level					1999	To Date		CEFA

[2] Source: FAO SWALIM archives

Two issues limit the usefulness of the Belet Weyne gauge for flood monitoring until a new rating curve is created. The site of the new gauge at Belet Weyne is at least 500 m away from the site of the prewar river gauge (John Cody[1], personal communication). The station at Bulo Burti is composed of a set of three plates that measure the river level from 0 m to 6.5 m. The gauge data are available from August 2002. The plates are situated on the left bank of the river downstream of the bridge. The staff gauge at Bardhere was installed without the aid of surveying instruments so the utility of the data is limited. The data from the Buaale and Jowhar stations are available from 1999. It is difficult now to use the river staff gauge at Buaale for flood forecasting because of the lack of a rating curve, and there was no pre-war river gauging station at Buaale. The quality of the Jowhar gauge is good and data are received daily by SWALIM.

At the time this report was written, SWALIM and partner organizations had re-established in operational mode 70 rain-gauging stations. (see Annex 1 for location of the gauges and the organizations that collect and transmitted the data to SWALIM). Most of the gauges were re-established on the same sites where the 65 rain-gauging sites were maintained by the National Water Centre of the Somali Democratic Republic's Ministry of Mineral Water Resources (MWR) before the war. The rain gauge installations schedule was guided by the security conditions present at sites and the availability of institutions to collect and transmit the data. The gauges are read once every 24-hr period. Additional rain gauges will be installed at the sites of River Stage Measuring Stations. The data from the re-instated sites are archived in the SWALIM database and form part of the Somalia Climate Archive. The locations of the existing stream and rain gauges and the institutions that record the data are listed in Annex 1.

The biggest shortcoming of the existing data collection network for river flooding or flash flood warning is the latency between data observation and data availability in the SWALIM office. None of the hydrometric or rainfall stations described above is an automated station or has a telemetric data transmission capacity. Most of the data are transmitted to the SWALIM office in Nairobi on a weekly or monthly basis; data with such latency have only a marginal use for flood forecasting purpose and even less for flash flood alert purposes.

3.3 Flood Forecasting and Early Warning Methods in Place

3.3.1 Hydrologic and Hydraulic Models in Use

SWALIM has experimented with running the regression equation described by Houghton-Carr and Fry (2002) for the Juba and Shebelle Rivers as a flood forecasting tool for predetermined locations along the two rivers within the Somalia borders. Houghton-Carr and Fry (2002) named their regression the Somalia Flood Forecasting Model (SFFM). The SFFM is an updated version of the RIVERF (Hydrometry Project-Somalia, 1990) another set of regression equations. The RIVERF was originally developed in the 1980s by the former Institute of Hydrology (now the Centre for Ecology and Hydrology) and the consulting firm of MacDonald and Partners.

The RIVERF and SFFM models forecast daily flow at downstream locations by using simple regression equations and observed flows at upstream locations from the forecast point. The regression equation coefficients were developed from observed flow data collected from 1963 to 1990. Based on the magnitude of the observed upstream flow for every forecast point, there are two sets of regression equations to choose from.

The lag time between the forecast locations is expected to remain constant throughout the year. The main difference between the RIVERF and SFFM models (apart from updating coefficients of the regressions equations) is that the first regression model was developed to be used with the DOS-based HYDATA software whereas the later was built around the Windows-based HYDATA v4.2. The equation of the RIVERF and SFFM models are of the type outlined below.

$$q_t^n = a\,q_{t-1}^{n-1} + b \qquad\qquad q_{t-1}^{n-1} \le q_{\max}$$

The q's are the discharge, and n and t denote location and time, respectively. The RIVERF and SFFM models have options for forecasting flow of a site by combining observed flow values from several upstream locations.

During the flood season, stream data from the re-established stream gauge stations (gauges at Belet Weyne and Bulo Burti on the Shabelle and at Luuq and Bardere on the Juba) are used by SWALIM to drive the SFFM to produce daily flood forecasts. SWALIM does not produce river forecasts during the weekend or public holidays.

There have been some inconclusive attempts at SWALIM to run the USGS GeoSFM hydrologic model (Artan et al., 2001) as a flood forecasting tool for the Juba and Shabelle Rivers. But the performance of neither the SFFM nor the GeoSFM as flood forecasting tools for the Juba and Shabelle Rivers has been evaluated by SWALIM in a systematic manner.

3.3.2 Weather Forecasting Systems

Flood forecasts based solely on rainfall observed up to the forecast time horizon carry an implicit assumption that no more rainfall will be falling within the forecast timeframe. Such a prediction will therefore be the worst possible forecast in the case of a severe rainfall event. To extend predicted stream flow into the future, the use of Quantitative Precipitation Forecast (QPF) data as input rainfall data is essential. Precipitation fields simulated from a variety of mesoscale weather forecast models can be used as QPF data by the future Flood Forecasting Center for Somalia and by the operators of the envisaged community-based flash flood alert systems. It is assumed that SWALIM will lead the processes of capacity building in flood forecasting and flash flood alert capacity in Somalia. For some time, the hydrologic modelling group at SWALIM has been using the NOAA National Centres for Environmental Prediction (NCEP) Global Forecast System (GFS) rainfall forecast product. The GFS is a global spectral data assimilation and forecast model system. GFS forecasts and guidance are generated every six hours at 0000, 0600, 1200 and 1800 UTC. For the GFS T382 product, the spatial resolution is 35 km and the forecast time is out to 180 hours. The GFS has temporal and spatial resolution we deem to be sufficiently high to be used as input to a rainfall-runoff model for the Juba and Shabelle basins.

3.3.3 Dissemination of Flood Warning Information

At this time, there is one major established user group for the flood warning product that SWALIM produces regularly during the flood season. This is the Flood Working Group (FWG) of the Food Security and Rural Development Sector Committee (FSDRSC) of the Somalia Support Secretariat (formerly known as Somalia Aid coordination Body – SACB), of which SWALIM is the co-chair. This group however, incorporates a number of UN agencies, international and local NGO as well as the representatives of the various government ministries in Somalia. In turn these agencies have contacts with a wider audience. SWALIM develops information sets to support flood preparedness and response plans prepared by the FWG, guided by the framework provided by the "Inter-Agency Action Plan for Flood Early Warning, Preparedness, and Response on the Juba and Shabelle Rivers in Somalia", SWALIM prepares storm and flood watch bulletins during the Gu and Deyr rainy seasons. The bulletins are sent through e-mail to partner organizations that include UN agencies and international and local NGOs that are based in Nairobi and in Somalia. The information in the watch bulletins is disseminated to a wider audience through the SFWG.

SWALIM combines the observed river water levels, at the previously mentioned hydrometric stations, with the NOAA satellite rainfall estimates (RFE) product and GFS rainfall forecasts that are provided by USGS in a weekly Flood Bulletin that is produced during the Gu and Deyr seasons. The bulletin is produced jointly with USGS/FEWS-NET. The bulletin is disseminated via e-mail distribution list to various actors in Somalia and Nairobi active in flood relief work, and the bulletin is made available via a Web portal hosted by SWALIM. The e-mail distribution list is continually updated.

3.4 Traditional Flood Early Warning Mechanisms and Alerts

In some of the riverine areas, people use numerous river level marks to monitor the onset of floods. People also use the colour of the river water as an indicator of the onset of large-scale surface runoff generation. When the water level in a river approaches warning levels, the news is disseminated by word of mouth and runners. For example, at Jowhar, when the Shabelle staff stage gauge reaches 5.25 m, the Middle Shabelle Authorities send messengers to the villages to warn the communities about the potential for floods[3]. At Jowhar they also make contacts with authorities at Belet Weyne and Bulo Burti for river levels information at those locations. Any flood forecast system that is put into place in the future should be tied to marks left by the major flood events, marks that are easily understood by large sections of the riverine populace.

3 Information obtained through personal communication with Nur Hussein, UNDP project engineer for Duduble canal rehabilitation project

3.5 Key Gaps and Weaknesses of the Current System

Currently no agency in Somalia has a mandate to forecast and issue flood warnings, and there is a lack of automated hydro-meteorological data collection and transmission system that are required resources for an operational flood forecasting centre. To establish effective flood forecasting capacities in Somalia, there is a need to develop the legal framework for the entity that will issue flood forecasts, the hydrologic modelling capabilities at such an entity, and the implementation of a real-time observing and transmitting hydro-meteorological data collection network.

Notwithstanding the lack of a legal framework in the last few years, SWALIM has assumed a lead role for monitoring the flood situation along the Juba and Shabelle Rivers. SWALIM uses an ad hoc procedure for flood forecasting and lacks needed field staff and resources dedicated for the purpose. SWALIM produces weekly and sometimes daily flood alert bulletins. A glaring weakness of the SWALIM flood alerting program has been the lack of an emphasis on disseminating the information in the flood bulletin to the flood-affected riverine population directly. It is not clear to us how useful the SWALIM bulletins have been to communities along the rivers. Disseminating the information in the SWALIM flood bulletin in Somalia through FM radio stations in the Somali language to these communities, in addition to the current practice, would be beneficial and needs to be explored.

4. TECHNICAL DEVELOPMENT OPTIONS

There are several factors to be considered when planning the implementation of a flood forecasting and warning system:

1) The availability of real-time observing hydro-meteorological data monitoring networks and financial resources to implement the system. Hydro-meteorological systems can range from a sophisticated weather radar-based system to a network of manually read gauges.
2) The extent of flood loss potential in the area and the frequency of flooding. The potential for loss of life and property and economic impacts could be so small or so infrequent that it might be hard to justify a large investment in a forecasting and alert system.
3) The availability of local trained personnel to sustain and maintain the system.
4) The effects of flood control structures on the river hydraulic characteristics.
5) The required warning lead-time. The meteorological conditions and nature of the basin's geomorphologic characteristics could combine to cause flooding to develop quickly, making warning lead-time insufficient for evacuation to take place.
6) The dissemination of the flood forecast warning and user's system requirements. An effective fail-safe forecast dissemination system must be established to allow forecasts and warnings to reach users with information that is meaningful to them, especially during flood events.

As part of this assessment, the factors listed above were considered in formulating what types of models and data acquisition equipment to recommend for the flood warning system for the Juba and Shabelle Rivers and the flash flood alert system for the towns of Garowe and Hargeysa. Both the flood forecasting and flash flood alert systems will require the installation of stream gages and rainfall recording stations at key locations. The data recorded by the stations will be transmitted to base stations in real time. The river flood forecasting system is designed to be able to forecast the arrival of floodwaters at specified locations along the rivers. With time, the system will allow the addition of new forecast locations along the two rivers.

4.1 Meteorological Networks

Equipment to measure and record meteorological variables (e.g., radiation, temperature, rainfall, humidity) varies from the traditional analogue or mechanical type to a multi-channel microprocessor-based apparatus. Data measured by mechanical or analogue means can be read manually or recorded as a continuous strip or event marks on a strip chart, with traces for the different variables plotted with different colour ink or a channel number written next to the trace.

Rainfall is the most important meteorological variable for monitoring floods and flash flood hazards; rainfall amounts are measured with rain gauges, ground-based weather radars, and satellite-based sensors. Each type of rainfall measuring method has its advantages and disadvantages.

The rain gauges are perceived to be most accurate way to measure amount of rainfall. The standard rain gauge consists of a funnel with an area of 100 cm^2 attached to a graduated cylinder that fits into a larger container. Rain gauges usually underreport the heaviest rains that fall from thunderstorms, which contain strong, gusty winds that blow a lot of the rain sideways over the top of the bucket. Also, because thunderstorms are often only a few miles in diameter, rain gauges (mainly located in major cities spread several tens of miles apart) often miss these storms, or are located on the edge. A significant amount of rain could go undetected.

A newer technique to measure rainfall is the weather radar. Weather radars can estimate rainfall in an area from 60 km to 500 km in diameter to give a more complete coverage than rain gauges. But weather radars have limitations: they do not measure actual rain but detect the amount of microwave energy scattered by water drops and ice particles moving through the air; statistical methods are required to correlate the amount of energy received with what is measured on the ground using rain gauges. These statistical relationships between radar-detected microwave energy and rainfall rate are not perfect, and they vary from location to location and even within then same storm system. Another limitation is that the curvature of the Earth limits how far the radar beam (which projects outward from the radar transmitter as a straight line) can detect rainfall, which is usually heaviest in the lower regions of the clouds. At large distances from the radar, the radar beam sweeps through the tops of the clouds and misses a lot of the rain. Studies have shown that radars and rain gauges often don't agree to within better than a factor of two. Finally, a disadvantage of adopting weather radar is the high cost; a unit costs from $100,000 to $1,000,000.

In last few years, satellite-based rainfall estimation is the method that is becoming more widely used for rainfall measurement. Satellites are able to provide a qualitative measure of the rainfall in an area, but it's difficult to measure rainfall from satellites with the accuracy of rain gauges because of the weak physical relationship between rainfall and the signal sensed by the satellites. Satellites still offer an effective and economical means for calculating areal rainfall estimates in sparsely gauged regions. Many satellite rainfall estimation techniques are in use. Most of the popularly used satellite-based rainfall estimation techniques rely on thermal infrared (IR) imagery of cloud tops, taken as frequently as every 30 minutes, to infer rain rate based on how cold the cloud tops are. Some other methods combine IR imagery with microwave radiation (MR) imagery, which measures radiation upwelling from the atmosphere. The MR absorption and scattering is physically more related to the amount of rainwater contained in a cloud. But MR suffers from a poor spatial and temporal resolution. Overall satellite-based methods are relatively new, and they are far from being perfect. A method that uses rain gauges to complement satellite-based rainfall data offers the most effective and economical way to monitor rainfall for Somalia.

4.2 Hydrometric Systems

4.2.1 Rating Curves

4.2.1.2 Acoustic Doppler Current Profilers

The traditional method of estimating discharge of a stream has been accomplished through the rating curve method. This method requires discharge measurements made over the range of stages of the stream to define the stage-discharge relationship. Discharge is usually measured with the velocity-area method by using mechanical current meters that generally require a minimum of 20 measurements across a river and take several hours to complete. Even when a rating curve is developed for a site there is a need to periodically update the curve because most streams experience processes that alter the stage-discharge relations, including processes like sedimentation and erosion of the streambed or banks, growth of vegetation along the banks, and aquatic growth in the channel itself. The USGS recommends a minimum of 10 stage-discharge measurements to keep rating curves up-to-date. The measurements should cover periods of low, high and medium flows.

A discharge measurement method that has gained ground in the last 10 years is the Acoustic Doppler Current Profilers (ADCP) system. ADCPs are either deployed over a small, remotely controlled catamaran or connected to a laptop operated from a boat. ADCP measures water velocity with acoustic energy and determines water depth by measuring the time-of-travel of signals reflected from the channel bottom. ADCP measurements are much faster than the traditional mechanical current meter methods; measurements are made in a matter of minutes rather than hours. To re-establish and keep updated the rating curves of the hydrometric station on the Juba and Shabelle River is of a high priority, for that to happen the deployment of ADCPs is essential.

4.2.1.2 Hysteresis of the Rating Curves

The Juba and Shabelle Rivers are both extremely flat, and could result in the stage-discharge relationship becoming not single-valued function (hysteresis). If the stage-discharge relationship is affected by hysteresis, the standard practice of fitting a single-valued rating curve to the available stage-discharge measurements is inappropriate. The applicability of using single-valued rating curves to estimate discharge for the Juba and Shabelle Rivers is not defined at the time of writing this report. For locations affected by hysteresis of the rating curve, the slope of the water surface can be different from that for a constant stage, depending on whether the discharge is increasing or decreasing.

Generally, the dynamic effect could be significant if the river bottom slope is less than 0.001 or when the rate of change of the stage level is greater than about 3 cm/hr, Fread (1975). Both rivers look to be places where a single-value rating curve will not work well, at least during a period of rapid rise of the water level, because the slope of the two rivers is about one order of magnitude smaller than what is suggested (see Table 1) for the applicability of single-value rating curves. Secondly, rapid stage rise has been observed in at least one instance on the Shabelle River (see Figure 4.1).

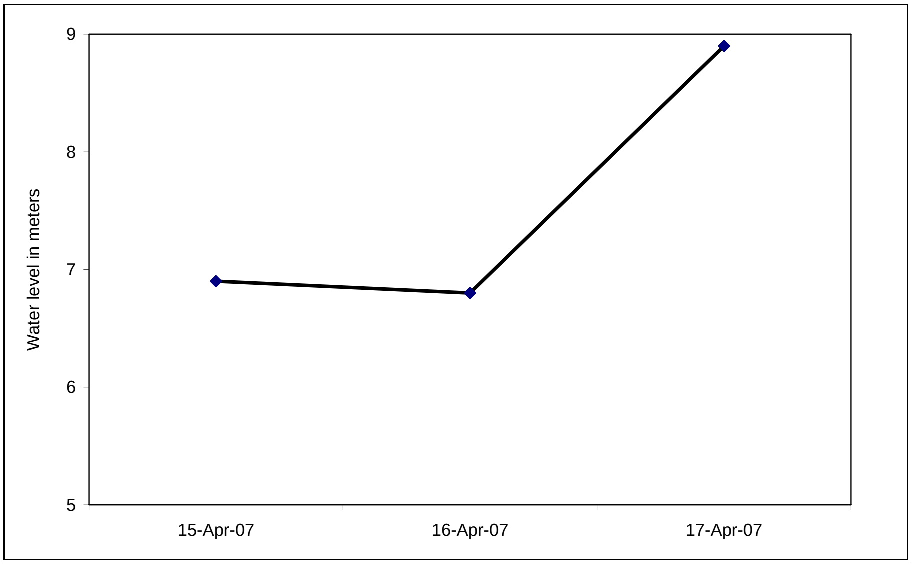

Figure 4.1: Observed Shabelle River water levels at Godey in Ethiopia

Figure 4.2 illustrates clearly what happens when hysteresis is present and a single-value rating curve is used. The estimated flows are underestimated during the rising phase of the flood wave and overestimated during the falling phase of the flood wave. The increase of flow in the rising phase-compared to the discharge estimated single-valued rating curves-is due to the surface slope in the river becoming greater than the slope for steady flow at the same stage; and hence, more water flows down the river than the rating curve would suggest.

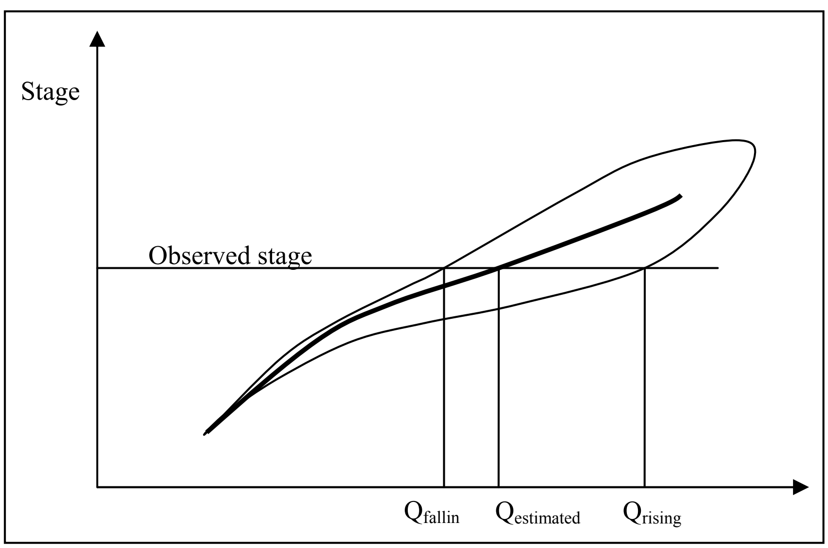

Figure 4.2: Hypothetical rating curve for a channel with actual true relationship of the stage and discharge showing hysteresis

The slope of the Shabelle River is quite similar to slope of the Red River between Fargo and East Grand Forks in United States. On April 16, 1997 the U.S. NWS issued a flood crest forecast for the Red River at East Grand Forks of 15.39 m for April 22. The river crested at 16.55 m, an underestimation of the flood stage of 1.16 m. A post-mortem analysis of the flood event revealed that 53% (0.61 m) of the forecast error was due to the use of single-valued rating curve where a looped rating curve was warranted. The usage of single-valued rating curve introduced errors when simulated flows are transformed into forecast river stage and observed stage levels are transformed into discharge and used to update simulated flows. Nowadays for the Red River, the NOAA National Weather services (NWS) has implemented a one dimensional unsteady flow forecasting model that is based on FLDWAV model. We can assume from the experience of the NWS that using single-valued rating curves for either of the Juba or Shabelle Rivers could result in a large uncertainty in the value of the estimated discharges.

We suggest that analyses of concurrent stage-discharge at a range of flows be carried for all locations where the hydrometric stations are proposed to be located. If the pattern of stage-discharge measurements shows a tendency toward hysteresis, corrective measures should be taken when estimating flows from stage measurements and vice versa. We suggest that correction based on the Jones-formula Henderson (1966), which requires no further data beyond the available stage measurements, be implemented. The Jones-formula is as given below:

$$Q = Q_o\left(1 + \frac{1}{S_o V}\frac{\partial y}{\partial t}\right)^{\frac{1}{2}}$$

Where Q_0 is the discharge according to the stage-discharge rating curve, V is the surface water velocity, and $\partial y/\partial t$ is the change in water height recorded between consecutive time steps/intervals (preferably hourly time step during flooding).

4.2.2 Simulated Rating-Curves

An alternative to using the rating curve developed from the velocity-area method is to develop a relationship between stage and discharge via a mathematical model based on the complete one-dimensional equations of unsteady flow, i.e., the equations for the conservation of mass and momentum of the flood wave (St. Venant equations), and the Manning's equation which accounts for energy losses. Numerical model calculated stage-discharge relations can well represent the hysteresis effects which are nearly impossible to represent by conventional methods. Such a rating curve, when used to convert observed stage into hydrograph, will properly reflect the unique dynamic of the stage-discharge relationship produced by the variable energy slope of a flood wave. Fread (1975) by using a model developed rating curves for stations along the Lower Mississippi, Red, and Atchafalaya Rivers in the United States, achieved root mean square errors between observed and computed discharges that were in the range of 3% to 7%, values that are well within the accuracy of the observations.

The decision to use rating curves simulated with hydrodynamic model or calculated with the velocity-area method should only be reached after adequate up-to-date stage-discharge data have been collected for every station. The measurements should cover all the ranges of low and high flows typically observed at each site.

4.2.3 Hydrometric Stations

River stages traditionally are measured with a stilling well. Stilling wells are located on the bank of a stream or on a bridge pier and are topped by a shelter that holds recorders and other instruments associated with the station. The well is connected to the stream by several intakes such that when the water level changes in the stream, the level simultaneously changes in the well. Building and guarding such structures in South Central Somalia would currently be extremely difficult. A new technique to measure water level that will lend itself well in application in Somalia is to use time-of-flight microwave radar to measure river levels. The radar sensor usually will make several measurements, average the results after a predefined time step, and convert the measurement data into stage levels in units of meters. Radar sensors are a solid choice for the Juba and Shabelle environment because of the smaller space they require. The radar sensor can be housed under existing bridges in weatherproof and tamperproof metallic cases. Several vendors of such radar sensors on the market claim to have radars that achieve water level measurement accuracy of ±3 mm, an accuracy that is quite good.

4.3 Hydrometric and Meteorological Data Transmission Systems

Using telemetry, it is possible to monitor and use real-time data collected by hydro-meteorological data acquisition devices located at remote sites. Several types of telemetry systems are in use for the transmission of hydro-meteorological data acquired at remote locations to a far base station. Three factors determine the best telemetry systems to use: distance to the base station, local conditions, and the cost of the system. There are many telemetry options to choose from, such as the Global System for Mobile (GSM) communication, landline, HF radio, short haul modems, telephone modems, Ethernet network, satellite, and the meteor burst system.

Data telemetry through radio is usually the first system of choice because of cost and convenience. The shortcoming of radio telemetry is that coverage distance is theoretically limited to only about 15 km, and because of interference by terrain, it is often necessary to use several repeaters on mountaintops between the data collection platform and the base station. For a network that should be implemented to support river flood forecasting, radio telemetry is not feasible because of the distance between the remote stations and the base station where the flood forecast model will be run and data are used. The flood forecast model will be run by a national level institution based in Nairobi (initially) or (eventually) in Mogadishu. Both places are too far away from gauging stations to use radio telemetry.

Another telemetry technology that could be used is the meteor burst telemetry system. The meteor burst system relies on the physical phenomenon that enables radio signals to be reflected off ionized meteorite trails 50 to 75 miles above the Earth's surface. Utilizing this principle, sites as far apart as 1,200 miles can communicate with one another for very short periods that are sufficiently long to "burst" relatively short data messages between sending and receiving stations. The U.S. Department of Agriculture Natural Resources Conservation Services (NRCS) has been successfully operating over 700 SNOTEL stations located in the western United States since the early 1980s. Major drawbacks for the adoption of the system include the high initial cost of the system; for example, the base station of the system costs about $130,000 and each remote station costs between $3,500 and $8,500. Two other drawbacks for the adoption of the meteor burst telemetry system are the high power requirement for the base station (up to 3.5 kWh) and the need for a large plot of land (at least 50 m x 50 m of land) to house the base station.

The adoption of a GSM-based telemetry system is problematic due to incompatibilities of the GSM systems that are operated at present by the multitude of mobile phone providers in different areas of Somalia and the unknown reliability of the system. Any telemetry system adopted should be robust and fail-proof. We cannot recommend a GSM-based telemetry system.

Satellite data telemetry service is available anywhere in the world. Data could be transmitted on a timed programmable schedule or transmitted whenever a preset threshold is reached. In Somalia, satellite telemetry provides the easiest and most reliable data telemetry option for hydro-meteorological network that will transmit data to distance longer than 50 km, where for the short distances HF radio offers the best telemetry option. Several satellite options are available for data telemetry (Iridium, Thuraya, Global star, etc.), and all of them offer data telemetry services with sufficient capacity for the use that the system we are suggesting will require. In addition, most of the data loggers sold by the major hydro-meteorological equipment vendors support most satellite telemetry systems. Deciding which satellite service to use should be based on the cost of the data services and the perceived sustainability of the service in the future.

4.4 Flood Forecasting Models

Floods can be forecast with complete rainfall-runoff models or with only routing models. The literature on flood forecasting is full of examples of both types of models being used adequately for flood warning purposes. Usually, routing methods-based flood forecasting models are simpler and less data-intensive. In the following section we will introduce a broad classification of various flood forecasting model types that fall under rainfall-runoff models and methods that rely only on the routing to downstream of an observed wave.

4.4.1 Rainfall-Runoff Models

Rainfall-runoff models can be classified broadly as black box models (e.g., stage-regression), lumped parameter models (e.g., Sacramento), and spatially distributed models (e.g., TOPMODEL). Black box models are based on transfer functions which relate inputs with outputs. Black box models, as the name suggests, generally do not have any physical basis; they rely on calibration to reproduce observed events. Lumped parameter hydrologic models treat the watershed as a single unit for inputting data and calculating runoff. The models are conceptually based and relate to the underlying hydrological processes as a spatially averaged process. A conceptual model where the watershed is subdivided into several sub-basins is termed a semi-distributed model. A distributed model simulates the hydrological processes using distributed data inputs and processes. Distributed hydrologic models require much more data than lumped models. Model selection depends on forecast needs, the characteristics of the watershed, and available data. It is usually harder to simulate catchment stream flow response for smaller basins and harder to simulate if they are located in an arid environment. It is harder to simulate in smaller basins because of the inertia of the system and in an arid environment because of the non-linearity of the relationship between rainfall and the runoff processes.

Complex physics-based distributed models do not necessarily result in better flood forecasting capabilities than simpler black box-type models. All the models need to be adequately calibrated before using. Proper model calibration is often constrained by the lack of calibration data of adequate quality and quantity. Hydrologic model calibration for the Juba and Shabelle basins is problematic because of the lack of a historical basin-wide meteorological dataset; there is a lack of such data even for the Somali portion of the basin alone. The only existing daily basin-wide rainfall data is the NOAA RFE (Xie and Arkin, 1997) dataset that has a high level of uncertainty associated with it. There are about four years of concurrent RFE and stream gauge data (for Juba and Shabelle), a length of time that is barely enough to calibrate a continuous hydrologic model, and that will leave no data for model verification purposes. A hydrologic model that has been adequately calibrated may not yield satisfactory forecast results during real-time operation, because of one or more of the following reasons:

(a) Inadequate representation of initial catchment conditions (e.g., catchment wetness)

(b) Inaccurate input data (e.g., rainfall data, QPF, and upstream river levels)

(c) Effects not considered by the model (e.g., river overflow into floodplains, effects of structures built after calibration)

(d) Flood forecaster’s lack of experience of the river system

If the future, because of the large areas involved and the wide difference in climate of the upper and lower reaches of the Juba and Shabelle basins, it will be necessary to use semi-distributed hydrologic models that incorporate remotely sensed data.

4.4.2 Flood Routing Methods

Flood forecasting methods that are based solely on routing of an upstream flow to a downstream forecast point can be classified as hydrologic or hydraulic methods. Hydrologic methods use the continuity equation only, whereas hydraulic methods use both the continuity and momentum equations. An example of hydrologic routing is the lag method; all hydrologic routing methods are lumped. The main advantage of hydrologic routing is its computational simplicity, and the main limitations of such models are their inability to simulate routing in flat channels, or channels with backwater effects, or to account for the effects of manmade structures on the flow. In contrast, hydraulic routing methods deal with such problems.

All hydraulic routing methods are based on the Saint-Venant equations (dynamic wave) or the simplified version of Saint Venant equations (kinematic or diffusion wave models). The two approximations have comparable accuracies to the dynamic wave equation if the river flow respects certain conditions. However, as the channel slopes become flatter the kinematic and diffusion approximation methods begin to break down. For both routing methods, the terms in the momentum equation that was excluded from the full dynamic equation become significant as the channel slope becomes flatter.

Kinematic flow occurs when gravitational and frictional forces achieve a balance. The application of the kinematic wave equation is limited to flow conditions that do not demonstrate appreciable hydrographic/flow attenuation in channels with steep slopes (slopes that are 10 ft/mile or greater). We can exclude outright the use of a routing method that is based on a kinematic wave approximation for the Juba and Shabelle because of the extremely flat slopes of the two rivers within the Somali borders.
The diffusion wave approximation of the full dynamic wave equations is a significant improvement over the kinematic wave model because of the inclusion of the pressure differential term, a term that allows the diffusion model to describe the attenuation (diffusion effect) of the flood wave. Since the diffusion wave approximation includes the pressure differential term in the momentum equation, it is applicable to a wider range of slopes than the kinematic wave equations (slopes approximately 1 ft/mile or greater). The Juba and Shabelle slopes are higher on average than the 1 ft/mile required for the validity of the diffusion wave; therefore, a diffusion wave type routing could be used to route the flood wave of the Juba and Shabelle. The Muskingum-Cunge routing method, a popular and widely available method, is also a diffusion-based method.

The basic data requirements for the various hydraulic flood routing techniques is generally the same; the differences are in the amount of detail. Usually the data requirements are as follows:

1. Discharge hydrographs from upstream locations as well as lateral inflow and tributary flow for all points along the stream,
2. Channel geometry cross section details, and reach lengths,
3. Stage-discharge relationship,
4. Channel roughness properties and slope,
5. Initial and boundary conditions,

In the absence of significant backwater effects (a condition that is true for both rivers), a diffusion-based routing model or an easily to calibrate black-box type routing method will offer the advantages of simplicity, ease of use, and computational efficiency.

4.5 Floodplain Effect on River Flow

The effects of the floodplains on the flood wave can be significant in both rivers. In both rivers, when the water level reaches bank full the flood wave is slowed greatly because of water ponding in the floodplains. The factors that determine the effects of the floodplain are the width of the floodplain, the slope of the floodplain in the lateral direction, and the resistance of the vegetation in the floodplain. In the future, to implement a hydraulic model of the Juba and Shabelle that could account for the flow transition from the main channel to the over bank flows, the modelling technique adopted should account for the varying conveyance between the main channel and the over bank areas. For 1-D flow models, this can be accomplished by calculating the hydraulic properties of the main channel and the over bank areas separately, then combining them to formulate a composite set of hydraulic relationships. These calculations will require building a database of the Juba/Shabelle floodplain characteristics and acquiring high resolution DEM datasets of the rivers' floodplains.

4.6 Real-Time Flood Forecasting

The basic components of any flood forecasting system are

1. a data collection and transmission network,
2. a flood forecasting model and updating model and,
3. a warning dissemination system.

For flood warning formulation, the data collected by the hydro-meteorological network are fed into the flood forecasting and updating models. The various flood forecasting centres around the world use different flood forecasting and updating models for the formulation of flood forecast warnings. Some of the common methods used for flood forecasting are

1. simple correlation—based on stage-discharge data or a co-axial correlation method that is based on stage-discharge and rainfall data,
2. routing of upstream flow to downstream forecast location (e.g., Muskingum-Cunge method) and,
3. Rainfall-runoff model.

The forecast obtained from any of the methods listed above is usually modified before arriving at a final forecast; the modification or updating is usually based on the prevailing conditions in the river and on meteorological conditions. There are various forms of forecast updating, depending on which variables are modified. Broadly, the updating may be done on model output (e.g., autoregressive model error correction), or the model internal states may be modified (e.g., Kalman filter type). If necessary, the flood forecasts, once issued, are further modified, and revised forecasts are issued if any additional information is received after the initial forecasts were made.

A large number of public domain and proprietary models are available for use as flood forecasting tools. The selection of a flood forecasting model for the two rivers should be based on the review of extent and quality of the available hydro-meteorological data, river characteristics, and the type of warning needed by the potential user community.

4.7 Updating the Flood Forecast Values

The updating of the forecasted flow is one of the main modelling ingredients of any flood forecasting system. Updating is needed to reduce unavoidable forecasting model errors, errors that could be caused by the uncertainty of the inputs (upstream flow, inflows, and rainfall) and/or the limitation of the rainfall-runoff model that was used. As explained previously, flood forecast updating can be done on the simulated flows directly, on the model input and state variables (e.g., Kalman filter), or on the model parameters (e.g., recalibration). As an updating methodology for the flood forecasting system of the Juba and Shabelle Rivers, we suggest the updating be done as one model output,

$$\overline{Q_{t+1}} = Q_{t+1} + \eta_{t+1}$$

Where the value of the forecasted flow is $\overline{Q_{t+1}}$, Q_{t+1} is the simulated flow value, and η_{t+1} is the value of the correction. The η_{t+1} error correction or updating value is determined from a function that uses previous errors of simulated flows and simulated flows as

$$\eta_{t+1} = f\left(\varepsilon_t, \varepsilon_{t-1}, \ldots, Q_{t+1}, Q_t, \ldots\right)$$

The ε_t values are the differences between past simulated and observed flows. For rainfall-runoff models, autoregressive models are the most-used updating tool and the easiest to calculate, Refsgaard (1997). The WMO (1992) study on the subject of flood forecast updating could not arrive at any conclusion on the best model to use for updating of hydrologic models. We suggest that the updating of the flood forecast of the Juba and Shabelle Rivers be an autoregressive-type function.

4.8 Issuing and Disseminating Flood Early Warning

Frequently, the lack of ability to disseminate warnings to the population at risk is the weakest link in flood forecasting and warning systems. The entire process of establishing a flood forecasting capacity is of no value unless the flood warning reaches the population at risk in a readable format and with sufficient lead time to permit response actions to take place. Establishing an appropriate flood forecast dissemination network and communication links will be extremely important for the success of any flood forecasting and warning program. For a flood forecasting dissemination system to be effective, it should be fail-safe and must allow for forecasts and warnings to reach people in villages, especially during flood events when there is usually a high probability of failure of communication systems.

Flood warnings from the system should be transmitted not only to the public at risk for flooding but also to the international organizations (usually based in Nairobi) that have been active in the flood response arena in Somalia. An effective flood warning dissemination program will therefore use a mix of communication forms and must be linked to the local media (especially radio). The mass media will provide an effective means for broadcasting flood warning communications to isolated communities that lack access to communication systems. Popular Somali radio outlets should be approached to gauge their availability to broadcast flood warnings when issued.

The appropriateness of the types of communication modes that we are proposing should be re-evaluated annually as experience is gained. The success and effectiveness of the flood forecasting and warning program will ultimately rest on how the communities at risk for flooding heed the warning when a flood warning or watch is issued. The response of this group of ultimate beneficiaries of the system will depend on how the warning is tailored to their needs at the design stage of the flood forecasting. To tailor the forecast to user needs, it is important that a survey is carried out on the kinds of data and information that the potential users of the system will need, and how they could best be reached with the warning.

4.9 Integrating the Components of the Flood Forecasting and Warning Systems

All data will be received by the central computer located at SWALIM offices in Nairobi. The data should be stored in a database where various types of quality control analysis and graphical displays are available. The database will be linked and be accessible to the flood forecasting modelling system. Automated quality control procedures, performed at the future FFC, will check to eliminate gross errors in data. For now till a specific flood forecasting model is chosen, we recommend the continuation of the use of the HYDATA database for archiving the hydro-meteorological datasets by SWALIM.

4.10 Evaluation of Routing Models

As a part of the preparation of this report, we did a preliminary evaluation of the forecasting skills of the SFFM, the Linearly Varying Gain Factor Model (LVGFM), and a Muskingum-Cunge routing. The LVGFM is a module of the Galway Real-Time River Flow Forecasting System (GFFS). The GFFS is a freely available software package that was developed by the Department of Engineering Hydrology, of the National University of Ireland, Galway. We tested the models in a hind cast mode to forecast river flows at the Bulo Burdi and Mahaday Weyn. The two locations had stream gauge data that were quality controlled in the pre-war period. The two locations were considered to be the easiest forecast points along the Shabelle, because of the lack of any significant structures on the river that could have altered the river flow characteristics between the two locations and the upstream sections of the river. Recorded river flows at Belet Weyne provided the input data to the model. For the same period and locations, we also tested the usability of a Muskingum-Cunge routing scheme as a flood forecasting tool.

The results from the evaluation were mixed. The SFFM proved to be a good forecasting tool for the Bulo Burdi gauge but had poor forecasting skills for the gauge at Mahaday Weyn. The Shabelle, as it travels downstream, becomes flatter with a reduced carrying capacity, a combination that makes the river prone to overflow into the floodplains, which have completely different hydraulic characteristics that the model cannot simulate properly. The Muskingum-Cunge was only a bit better than the SFFM. The LVGFM exhibited the best forecasting skills of the three tested models (see Figure 11a-c and Table 3).

The LVGFM while quite simple to set up and calibrated it gave an excellent performance in simulating both the timing and magnitude of the stream flow for the section of river between Belet Weyn and Bulo Burti; model performance for the reach between Bulo Burdi and Mahadey Weyn was good. It is our opinion that with only few adjustments of model parameters to account for the peculiar hydraulic conditions of the river, model stream flow predictions skill for the area lower than Mahadey Weyn could be increase from good to excellent. We did not simulate the flow of the Juba River, but the Juba system being simpler than the Shabelle River, hydraulically speaking; the above results modelling results should also be true.

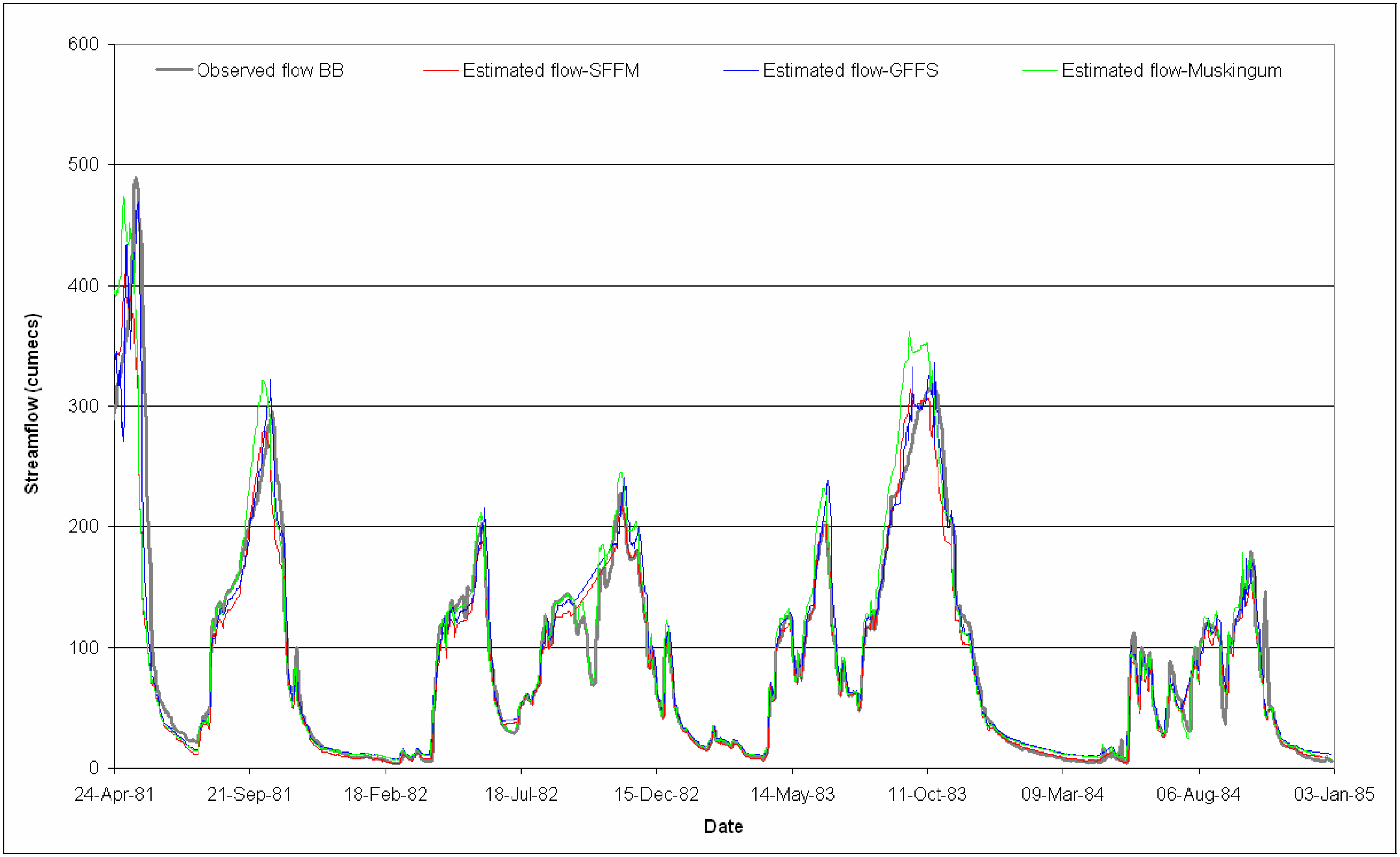

Figure 4.3a: Observed and Estimated Flow for Bulo Burti

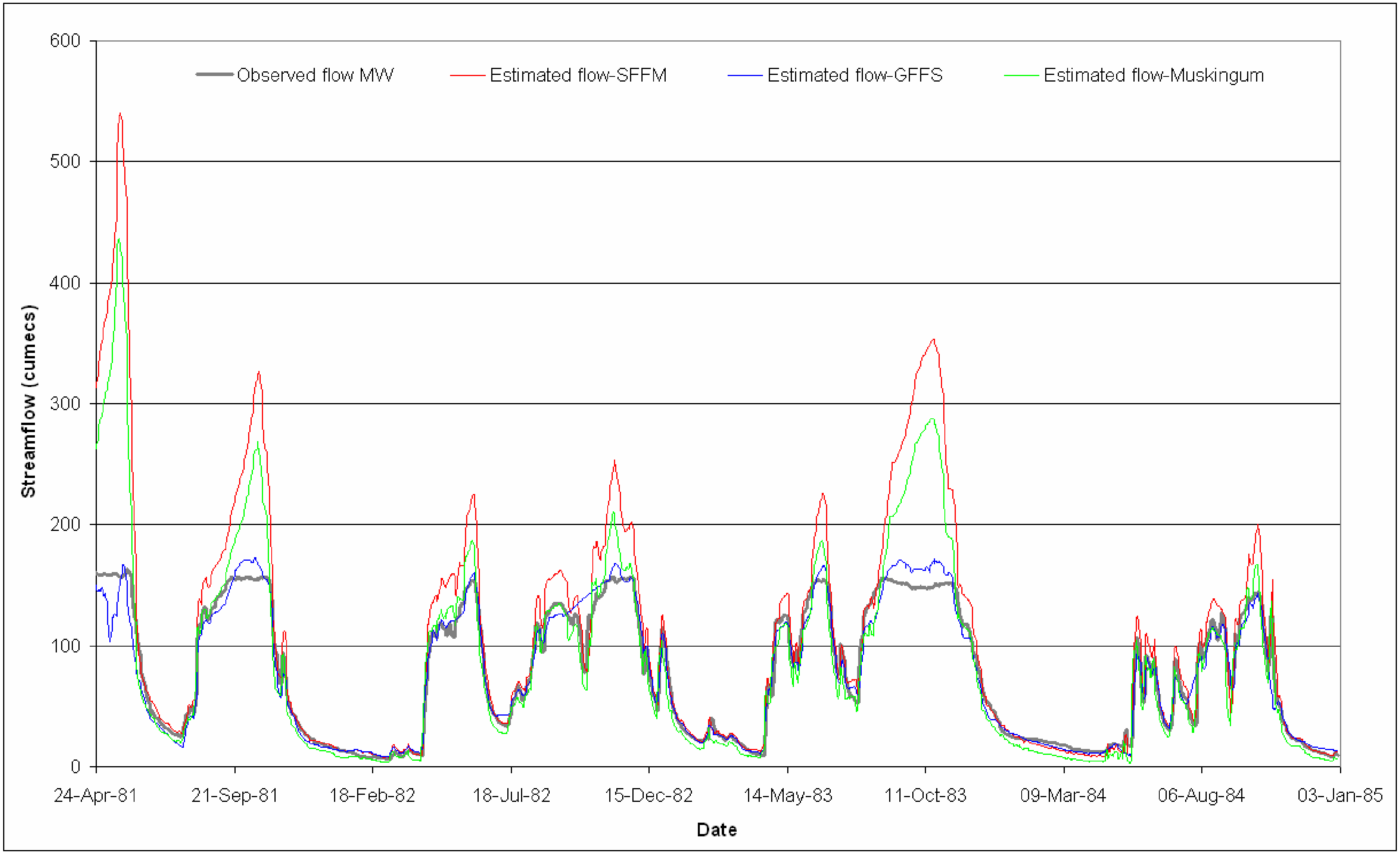

Figure 4.3b: Observed and Estimated Flow for Mahadey Weyne

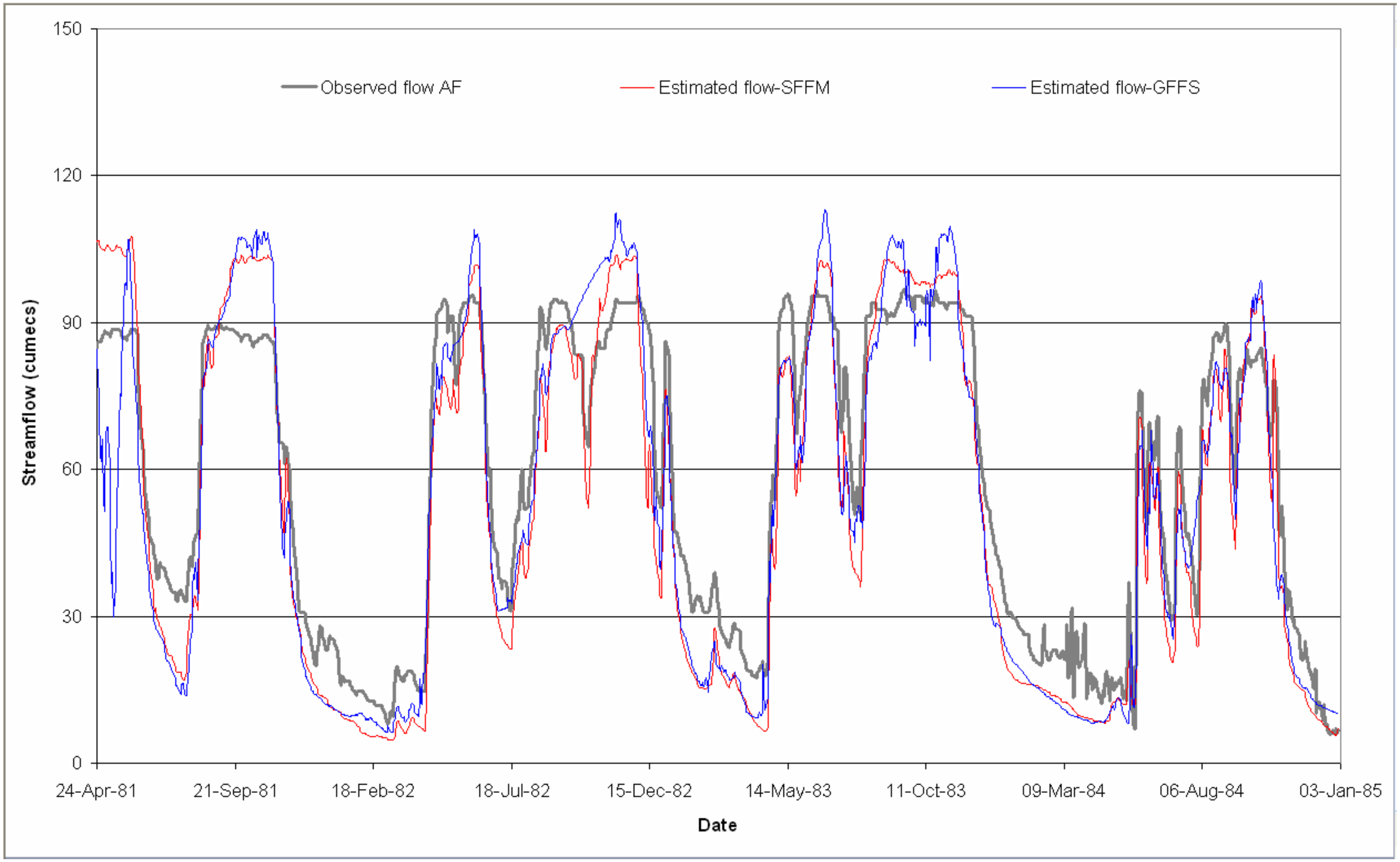

Figure 4.3c: Observed and Estimated Flow for Afgoi

Table 3:. Correlations for the observed and estimated flow for selected stations

Gauge Station	Somali Flow Forecasting Model (SFFM)	Galway Flow Forecasting System (GFFS)	Muskingum Cunge Routing
Bulo Burti	0.92	0.95	0.90
Mahadey Weyne	0.80	0.94	0.81
Afgoi	0.92	0.89	-

5. FLASH FLOOD ALERT SYSTEM FOR NORTHERN SOMALIA

5.1 Introduction

A flash flood is "a flood that rises and falls quite rapidly with little or no advance warning, usually as a result of intense rainfall over a relatively small area."[4] Flash floods may occur suddenly and be accompanied by other hazards such as landslides, mud flows, damage to infrastructure, and even death. During the last two decades, northern Somalia has experienced several serious flash flood disasters in different parts of the region that have resulted in damage to property and loss of lives. The region has a hot and arid climate and a short rainy season with occurrences of intense rainfall events that can result in flash floods. Flash flood events frequently trigger disasters in the area because of the lack of warning and prevention measures in place.

Since 1991, there has been no real-time hydro-meteorological monitoring and reporting network in the region because of the limited capacity for rainfall monitoring and forecasting of the existing administrations of the region (Somaliland and Puntland). The region has a network of manually read rain gauges that has been established in last few years. The network was established by the SWALIM project at key locations to strengthen the capacities of the Ministries of Agriculture of the two regions. But the needed improvements of the hydrological data collection and information management systems and the capacity for hydrological monitoring services have not occurred for budgetary reasons. The result is a lack of a baseline data and information for flash flood alerts system. Establishing a flash flood alert system designed to meet the needs and requirements for alerting populations at risk provides the best solution and most cost effective way, compared to structural measures, to alleviate the humanitarian conditions created by flash floods in the regions.

5.2 Impacts of Flash Floods in the Region

Recent information received from the Ministry of Public Works in the Puntland region indicates that flash floods cause severe damage to the region's infrastructure. A flash flood event that occurred in May 2005 destroyed a large section of the Garowe-Bosaso road (Ministry of Public Works, 2005[5]). The road was reported to have remained impassable for several days (see Figure 5.1). In Somaliland, specifically in Hargeysa city, one of the two main bridges was washed away in April 2005, leaving many parts of the city inaccessible. Figure 5.2 shows a major bridge on the Madoori Jeex Wadi in Hargeysa that was washed away during the flash flood of May 2005. An interagency assessment estimated that these floods affected slightly over 1,000 families (Nissen-Petersen and Muthigani 2005[6]).

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[4] www.weather.com, 2002

[5] Information extracted from a presentation obtained from SWALIM database and that was obtained through personal communications with Eng. Khalif, Director General of the Ministry of Public Works in the Puntland State of Somalia.

[6] The bridge does not currently exist – See photo above extracted from a report by Nissen-Petersen and Muthigani (2005) showing the bridge before it was washed away.

Figure 5.1: Impacts of May 2005 flash floods on a section of the Bossaso highway in the Puntland area[7]

Figure 5.2: Bridge in Hargeysa on the Marodi Jeex Wadis that was washed away during the flash flood event of May 2005

In October 2006, the capital of Togdheer region, Burao town, experienced severe flash floods, resulting in extensive damage to property[8]. Burao is situated on the banks of the largest wadi in Togdheer region (See section 5.4) with the same name. The town lay on land that is prone to flooding. Before the civil war, several structural flood protection measures were in place with a wadi embankment built on the southern and western areas of the town. In addition, several dams were built upstream of the town to attenuate the peak of the flood wave.

[7] Photos obtained from a presentation made to SWALIM by the DG Ministry of Public Works in Puntalnd.

[8] Extracted from a draft report on flood-affected people in Burao Town, an assessment mission carried on October 20–22, 2006.

The most recent flash flood event in Somaliland took place on April 14, 2007, in Allaybaday, where 87 earth dams out of the 105 dams that are used for supplemental irrigation were destroyed and washed away, with farm fields being inundated and irrigation infrastructure destroyed[9]. No human casualties were reported, only livestock deaths. The destroyed dams supported the livelihoods of about 10,000 people.

Figure 5.3: Impacts of Allaybaday flash floods: a photo of a broken sand dam in the area due to a recent flash flood[10]

In many parts of the region, most of the domestic water sources across the seasonal dry riverbanks and flood plains are contaminated due to the flooding, causing drinking water scarcity and, in many cases, raising concerns for the outbreak of water-related diseases. For example, due to the flash floods that occurred in April 2005, the only public water supply system to Hargeisa city has been under threat due to flooding by weakening of some of the bore-wells. A number of houses and business establishments along the banks of the wadi were either fully or partially destroyed (Nissen-Petersen or Muthigani 2005).

5.3 Major Reasons and Causes

Besides the spatial and temporal variability of rainfall, the following reasons are considered the main factors behind many of the flash flood problems in the region:

(a) absence and lack of efforts to regulate and manage seasonal river flows
(b) land degradation and soil erosion caused by felling trees from river banks, thereby weakening them
(c) Improper practices of rain water collection
(d) absence of urban land use planning, management, and legislation with the results that homesteads and businesses have been sprouting along the river banks
(e) lack of proper drainage systems in urban centers
(f) lack of maintenance of the flood protection dikes
(g) absence of community awareness

[9] Information extracted from Joint Flood Assessment Report of Alleybaday Agro-pastoral communities conducted on April 2007.
[10] Photos are extracted from an interagency assessment report conducted on April 18. SWALIM team together with a local NGO also visited Allaybaday area on May 1, 2007

5.4 Problem Statement

5.4.1 Flood Vulnerability of Garowe City

Garowe City is the capital city of Nugal region and Puntland state of Somalia. With a population of almost 50,000 and lying on the main highway to Bossaso, Garowe City is of great importance and its protection from flash floods is urgently needed by the Puntland authority. The main stream[11] (togga) draining into the city is one of the tributaries of the Nugal Tog and it originates from the southern part of the region. The area of the basin is estimated at less than 600 km^2 with little information available to define its relevant characteristics compared to the Hargeysa River.

Even though Garowe City and the surrounding areas are hot and dry, the city has experienced several destructive floods during the past few years (e.g., 2004 and 2005). Several reasons explain the city's frequent flooding predicament. The city extends along and borders the main stream (Figure 5.4). Despite that area rainfall is usually low, with annual rainfall averaging only around 130 mm, there is the possibility of an amount equivalent to the total annual rainfall falling in few days or even in a single day. Due to the basin's vegetation and soils and their inability to store water and their low infiltration capacity, more of the rainfall becomes runoff than in other basins of comparable size. Although runoff is high, a great portion of it evaporates in the flat lands.

Apart from the loss of lives and the injuries suffered by people, the flood also negatively impacted the economy, with substantial damage to both public and private structures. The highway to Bossaso was temporarily closed after the collapse of a bridge in the vicinity of the town. Public health risks were created or made worse by the destroyed sewage pipes. Another main bridge in Garowe city was overtopped during the May 2005 floods and other severe damage was reported.

Vulnerability to floods is defined as the degree of loss to a given community resulting from the occurrence of a flood disaster. Some of the communities closest to the togga are the poorest neighbourhoods of the city and accordingly the least prepared and the most vulnerable to the effects of floods. Many IDPs and informal settlements along the togga pass beside the city (Figure 5.4).

[11] The catchment boundaries are delineated using a 90m DEM obtained from USGS.

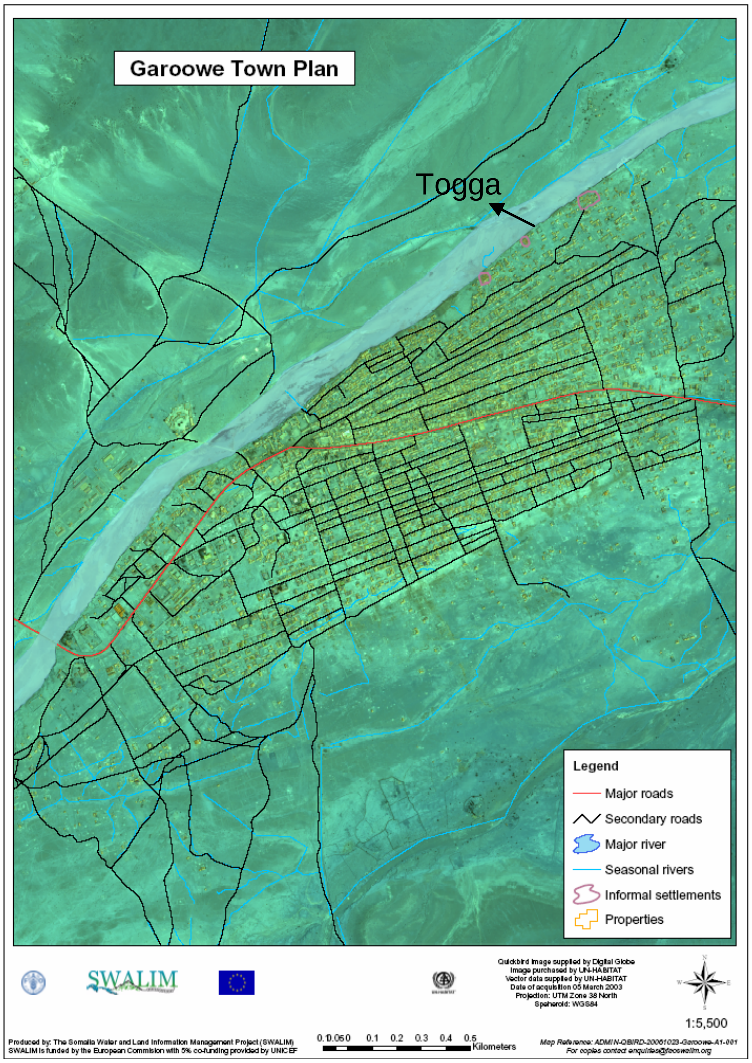


Figure 5.4: Garowe Town Plan produced using Quick-Bird Satellite image acquired for March 2003[12].

Structural flood controls might reduce the flood vulnerability of the neighbourhoods on the left bank of the togga more than the right bank areas. Although the left side neighbourhoods are sparsely populated, some people will still be vulnerable to flooding. At the time of this study, we were unable to perform inundation mapping simulations due to the lack of high resolution topographic maps of the area, but no doubt a large part of this area could be inundated, especially the hospital and university, if the togga flows reach high discharge levels (see Figure 5.4). The population of this area will benefit the most from the establishment of a flash flood alert system.

[12] The current city is much bigger compared to the 2003 city. Due to lack of stability in the country, many people have decided to settle in Garowe city. From a small village along Bossaso highway, Garowe today has high rise buildings.

5.4.2 Flood Vulnerability of Hargeysa City

Hargeysa City was considered the second largest city in Somalia before the war. The city is the major capital of the Somaliland and Wagooyi Galbeed region with a population of 500,000 to 700,000 people. The city has grown in the past 10 years mainly because many people from the south and east of the country have migrated to the city due to the political stability in the region. The main stream draining the city is Togga Maroodi Jeex, which divides the city into two major localities. High numbers of people live around the floodplain, increasing the vulnerability to flooding especially among the poor and the IDPs. The city lacks planning and land use legislation. With the result that many people have built in the floodplains of the Togga Maroodi Jeex, increasing the vulnerability of lives and assets to flooding, Figure 5.5.

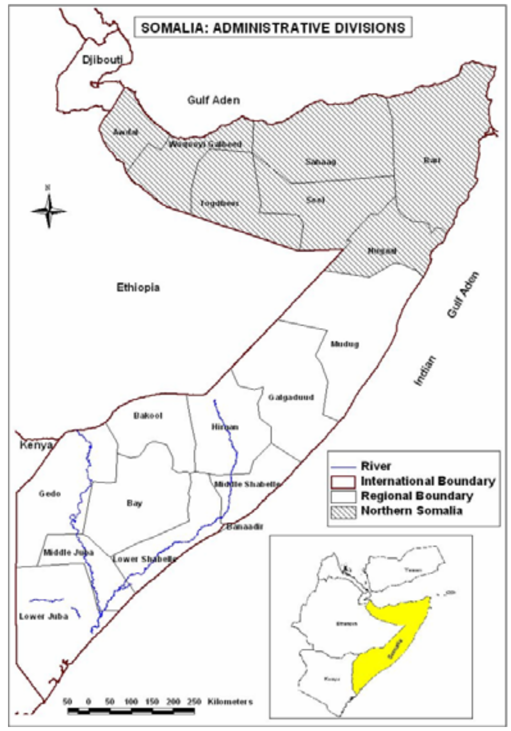
Figure 5.5: Hargeysa Town Plan produced using Quick-Bird Satellite image acquired for November 2004

5.5 Characteristics of the Area Concerned

5.5.1 Physiographic and Hydrologic Features

Northern Somalia covers the following regions: Awdal, North West Galbeed, Togdheer, Sanaag, Bari, Sool, and Nugal. Northern Somalia has a morphology that is more complex than southern Somalia, and it is traversed by the Golis range.

The eastern area is characterized by mountainous areas, plateaus, and valleys. Numerous streams have incised the mountainous area; those draining into the Gulf of Aden have a predominantly southeast to northwest direction, and those discharging their waters into the Indian Ocean have a west to east direction, among which the Togga[13] Dhutand and Togga Nugal are the most important. The Togga Dhutand's terminal section (Togga Jaceyl) drains the Darror valley, located south of the northernmost mountainous area. Its drainage system extends from west to east over a length of 350 km, covering an area of over 25,000 km^2 which ranges in elevation from 1,500m to about sea level. The Togga Nugal has deeply incised the southern part of the eastern area; it has a catchment area of 70,000 km^2 and drains the Nugal region and parts of the Togdheer and Sool regions.



The central area is marked by the Golis range, which runs parallel to the shore of the Gulf of Aden. The highest peak is Mount Surud, with an elevation of 2,408 m. The mountain range is deeply incised by numerous toggas flowing toward the Gulf of Aden. With the exception of the coastal belt, the remaining area forms a large plain sloping gently southward where it meets the Bokh and the Nugal valleys.

The western area is characterized by a large, gently undulating plateau, covered mainly by sedimentary rocks south of Hargeysa city. North of this plateau a mountain range extends from Lafwuug to Agabar and Borama. The northernmost part of the western area is constituted by the sloping plain and coastal strip which extends along a large belt ranging in elevation from 600m to sea level. There are four major basins in the western area: Togga Waheen, Togga Durdur, Togga Biji, and Togga Silil, with respective catchments of 3,000, 3,850, 3,560, and 1,930 km^2 (Faillace & Faillace 1987). Rainfall varies considerably from one basin to another.

[13] Togga is the Somali name for a seasonal stream

5.5.2 Soils and Vegetations

Soil composition in north eastern Somalia and the arid and semi-arid conditions of the area are the main factors which in the past have limited agricultural development, leaving the land mainly for livestock grazing. Large parts of the western area are covered by deep soils generally of fine texture which are subject to erosion. Soils become increasingly sandier towards the southwest, where rainfall decreases and vast areas are covered by gypsiferous soils. Wind erosion of this powdery white soil is continuous and plant coverage is limited to low density grass. Large areas have various rock types outcrop. These areas are denuded of the soil mantle and they form the headwaters of the toggas. Erosion here is mainly caused by runoff water.

In the coastal plain the vegetation is scanty and constituted mainly of scattered small bushes and grass, with an increasing density of thorny bushes toward the base of the mountain range (Faillace & Faillace, 1987). At altitudes between 1,000 and 2,000m, vegetation thickens and the area becomes savannah or open woodland. The top of the mountain range is covered by evergreen trees of the juniper forests.

5.5.3 Climate

The climate in northern Somalia ranges from very arid to semi-arid to temperate. Figure 5.6 shows the mean annual rainfall distribution in the area. The map is produced from the FAO SWALIM historical archive and indicates that the western regions of the areas are the wettest, with mean annual rainfall reaching up to 700 mm. Elsewhere the eastern areas receive little rainfall with the exception of Ceerigabo which receives almost 600 mm per year.

Rainfall varies considerably from one year to another, ranging in intensity from drizzle to downpours. It rains mainly from April to September. Violent local storms lasting one or two hours occur in the mountainous areas, leading to flash floods in low-lying lands. Little rainfall occurs along the coast. Seasonal temperature variations are quite marked along the coast, ranging from as high as 45 ^{0}C during the summer to about 25 ^{0}C during the winter. Seasonal and daily temperature variations are quite accentuated in the mountainous areas. The temperature gradient increases by an average of 0.8 ^{0}C/100 m from Hargeysa on the plateau to Berbera on the coast. Relative humidity along the coast may reach values greater than 90% but generally varies between 50% and 85%. In Ceerigabo the relative humidity is much lower, ranging from 34% to 70%, while evaporation is estimated to vary between 2,000 and 3,000 mm/year, Faillace & Faillace (1987).

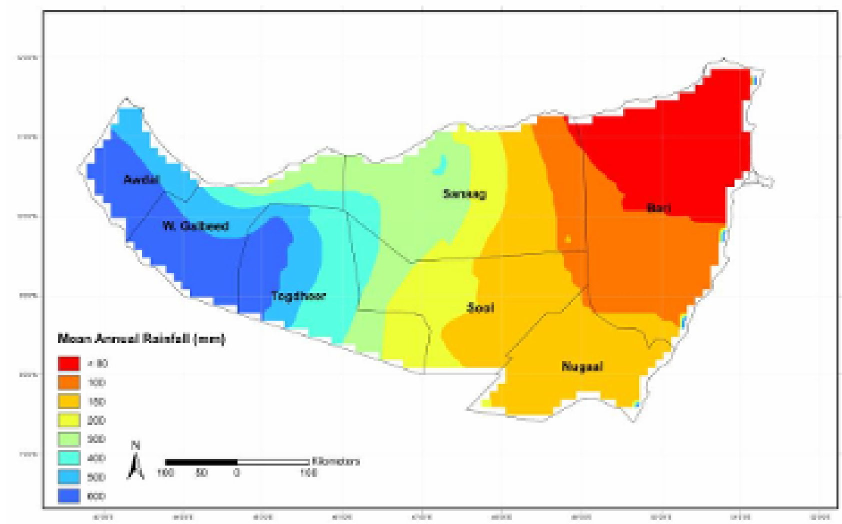


Figure 5.6: Mean annual rainfall for northern Somalia region

5.6 Technologies, Approaches and Proposed Hardware and Software

Due to the limited resources available for the task there were not many options available when considering the feasibility and implementation of flash flood alert systems. The type of flash flood warning system selected has considered the factors listed below.

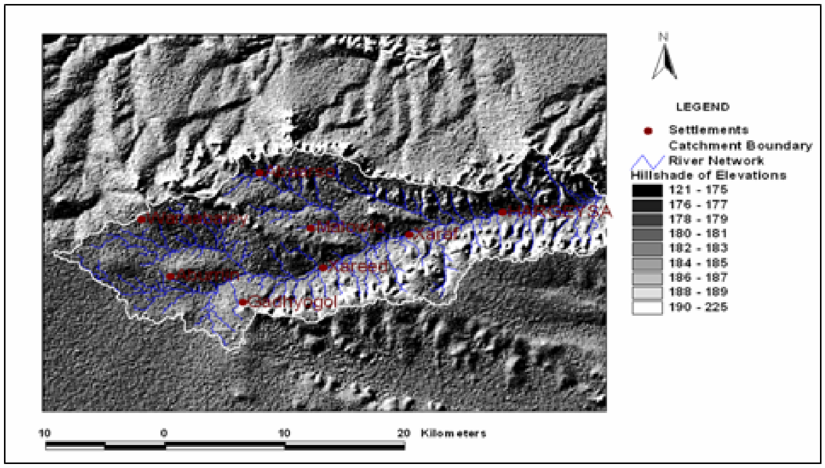
1) Hydrologic characteristics of the basins;
2) meteorological conditions that can cause flooding; if the area is prone to intense limited areas rainfall implementation of a flash flood alert system becomes difficult.
3) Frequency of flooding and the impact of flash floods; if the impact is severe and frequent warrant the implementation of a warning system.
4) Warning time needed to prevent “significant” impacts; the short the more difficult it becomes. .
5) Availability of personnel to operate the system.
6) Available hydro-meteorological monitoring networks.
7) Sustainability and maintainability of the system when implemented

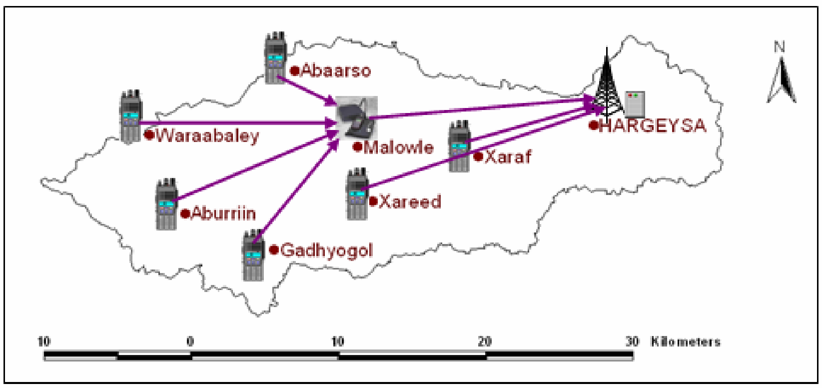
As part of this study, the factors listed above were considered in the evaluation of the various technical alternatives for flash flood alert systems for the seasonal streams draining into Garowe and Hareisa towns in northern Somalia (no other watersheds were considered in the evaluation). The evaluation also included a review of previous assessments and mitigation options and evaluations done to determine solutions to the flash flood problems in Hargeysa city.

This evaluation yielded a flash flood alert system that is based on in-situ hydrometeorological observing network (automatic rainfall and stream gauge stations) and remotely sensed rainfall data. . The hydrometeorological network systems will measure current conditions in the watershed and then provide a rapid assessment of critical threshold indicators for rainfall rates and/or stream water levels. The alert system then triggers appropriate alarms when these meteorological and/or hydrologic thresholds and conditions are exceeded using a preset flash flood guidance values. There are many parts of the world where similar community-operated flash flood alert systems (known as ALERT – Automated Local Evaluation in Real Time) (Gadain et al., 2006) has been operated successfully. Community involvement in the operation of these types of warning systems was not considered practical for this study, but awareness and education is an integral part of these systems, which have high potential in the northern Somalia context. The two cities have a large number of mosques with loud speakers, where if tied up to the ALERT in the event of incoming flash flood the signals can be sent to the public. If implemented the ALERT system would be maintained and monitored solely by appropriately trained representatives of identified agencies. Human involvement is at a minimum, especially in data collection and transmission. Flood data analysis and dissemination should be carried out by experienced staff. Sending wrong signals is expensive in terms of evacuation.

ALERT systems are composed of an automated monitoring network of a combination of rain and stream gauges. In addition to the monitoring network, the ALERT system has a computer-based station where data from the sensors are received, analyzed, and archived. The software in the base station analyzes the sensor data for pre-determined critical thresholds of rainfall and/or stream level and, if these thresholds are exceeded, triggers an alarm of some type to alert the operators – e.g., audible, visual, fax, or telephone call, or/and a signal to mosques loud speakers. The operators of the system must then make a quick evaluation of the situation and notify the appropriate authorities or issue warnings directly. The location of the base station is critical – it must be able to receive data from the network and be monitored 24 hours per day, seven days per week, during times when flooding is possible. ALERT systems usually include a hydrologic modelling component to provide forecasts of water level and the timing of the flood wave at critical locations. The hydrologic forecast modelling system, when used in conjunction with the monitoring network, requires trained personnel with hydrologic and/or meteorological background to operate it and add value to its outputs (e.g., more information and fewer false warnings or missed warnings).

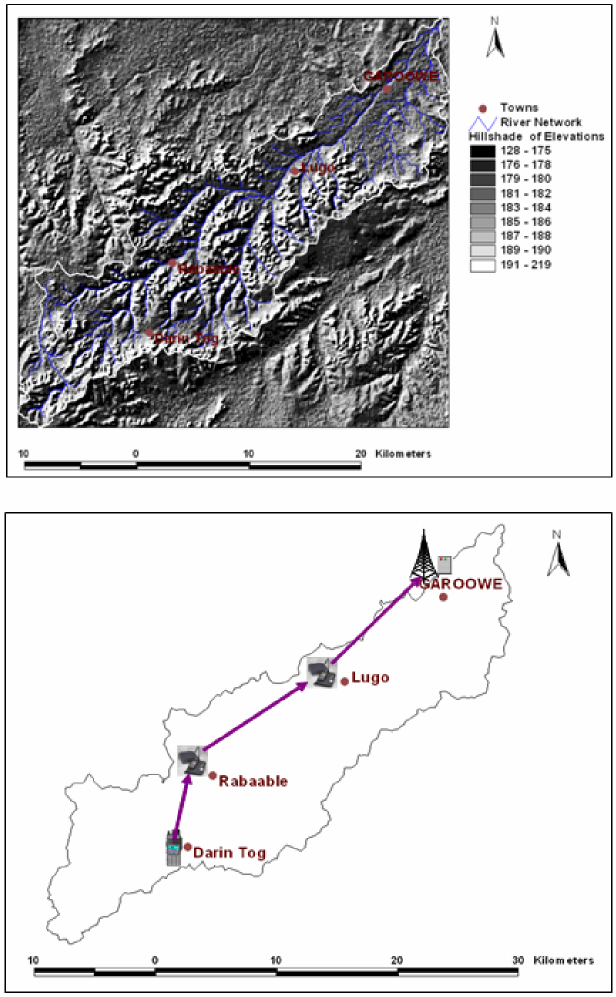
Requirements for the number and location of rainfall gauges in the monitoring network are outlined in Figures 5.7a-b. The network was design to best capture the spatial variability of the rainfall in the basin and to give enough warning time for the stream gauges. Data transmission for all sensors in the network will be through a line-of-sight radio signal. During the implementation of the systems, given the terrain and topography, repeaters may be required to relay signals to another repeater or to the base station if direct line-of-site is not possible.





Station	Rain Gauge	Stream Gauge	Radio Repeater	Base Radio Station
Waraabaley	✓			
Aburriin	✓			
Abaarso	✓			
Gadhyogol	✓			
Xareed	✓	✓		
Malowle	✓		✓	
Xaraf	✓			
Hargeysa	✓			✓

Figure5.7a: Proposed locations of rainfall and stream gauges sensors for Hargeisa



Station	Rain Gauge	Stream Gauge	Radio Repeater	Base Radio Station
Darin Tog	√			
Rabable	√			
Lugo	√	√	√	
Garowe	√			√

Figure5.7b: Proposed locations of rainfall and stream gauges sensors for Garowe

5.7 Flash Flood Guidance

The installation of the rain and stream gages alone will not be sufficient to issue flash flood warnings. To issue flash flood warnings for Hargeysa and Gorowe, Flash Flood Guidance (FFG) values for all the major sub-basins of the Garowe and Marodi Jeex Toggas need to be fixed. FFG is the average rain needed over a basin during a specified period of time to initiate flooding in the streams that drain that basin. The FFG value is usually determined by the rainfall intensity and is controlled by the status of the soil moisture. In Northern Somalia, due to rock outcrops that cover large areas around the cities of Hargeysa and Garowe, the occurrence of flash flooding events are influenced more by intensity of the rainfall, and are less correlated with the antecedent conditions of the soil moisture.

Preliminary values of FFG that are independent of soil moisture conditions for Toggas that transverse Garowe and Hargeysa can be calculated according to Sweeny (1992) as:

$$FFG = \frac{\mathrm{Q_p}}{\mathrm{q_{pR}\,A}}$$

where Q_p is the bank full flow, q_{pR} is the unit hydrograph peak flow, A and is the drainage area. Since neither of the basins has observed stream flow data available, Q_p should be determined from Manning's equation using a shape parameter for hydraulic radius:

$$\mathrm{Q_p} = \frac{1.486 * \mathrm{S}^{0.5} * \mathrm{B_b}}{\mathrm{n}} \left(\frac{\mathrm{y_b}}{\mathrm{m}+1} \right)^{5/3}$$

where S is the channel slope, B_b is the channel bank full width, y_b is the channel depth at flood stage (we have used a threshold value of 60 cm), n is the Manning's roughness coefficient, and m is the shape parameter of cross-section (0 for rectangular, 0.2 for bowl-shaped, 0.5 for parabolic, 1.0 for triangular and 1.5 for triangular with convex-shaped banks, in our case we assumed a rectangular shape). The Q_p value will need to be validated in the future with field survey channel cross of the two Toggas. The variable q_{pR} can be calculated with the Geomorphologic Unit Hydrograph (GUH) approach as:

$$\mathrm{q_{pR}} = \frac{640\mathrm{C}_p}{0.955 * \left(\frac{L * L_c}{S^{0.5}} \right)^{0.38} + 0.25 * t_r}$$

Where C_p is a coefficient that ranges from 0.4 to 0.8, L is the length of stream from point of interest to the stream's uppermost end, L_c is the length of stream from point of interest to the centroid of the basin, t_r is rainfall duration, where A is the drainage area upstream of point of interest, and S is the local channel slope.

We produced FFG values for 3 time intervals (1, 3, 6 hours) using the formulas described above (see Figure 2.8a-b for values of FFG). The parameters of the two basins channels were prepared using the GeoSFM model Arc View interface.

Flash flood warnings should be issued whenever observed rainfall rates exceed the FFG value in one of the three defined time periods. Warnings should also be issued when 10 cm of flood water is measured by the installed stream gages. The FFG are not in any way a "gospel", but should be seen only as guidance; if the forecaster believes that a warning should be issued before the rainfall rate exceeds the FFG value a warning should be issued. At the present time, we are of the opinion that more complex flash flood warning models are not warranted for the area because the limited technical capacity of the two regional administrations and short lead-time of flash floods (that does not lend to be forecasted by a forecaster based in Nairobi in the manner that will be done for the forecast of the river floods) precludes any complicated modelling setup.

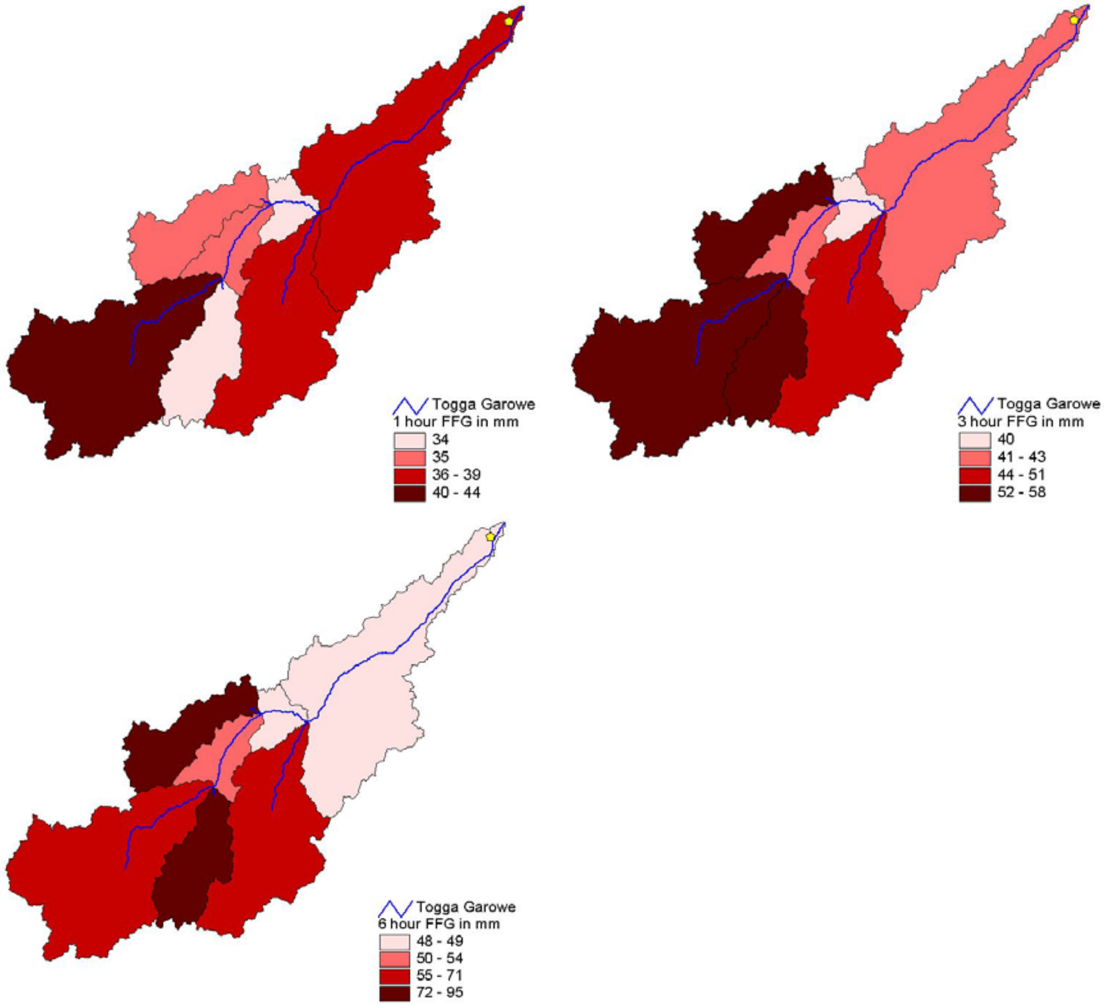


Figure 5.8a: Flash Flood Guidance values for the Togga Gorowe and tributaries for one, three, and six hours duration rainfall events

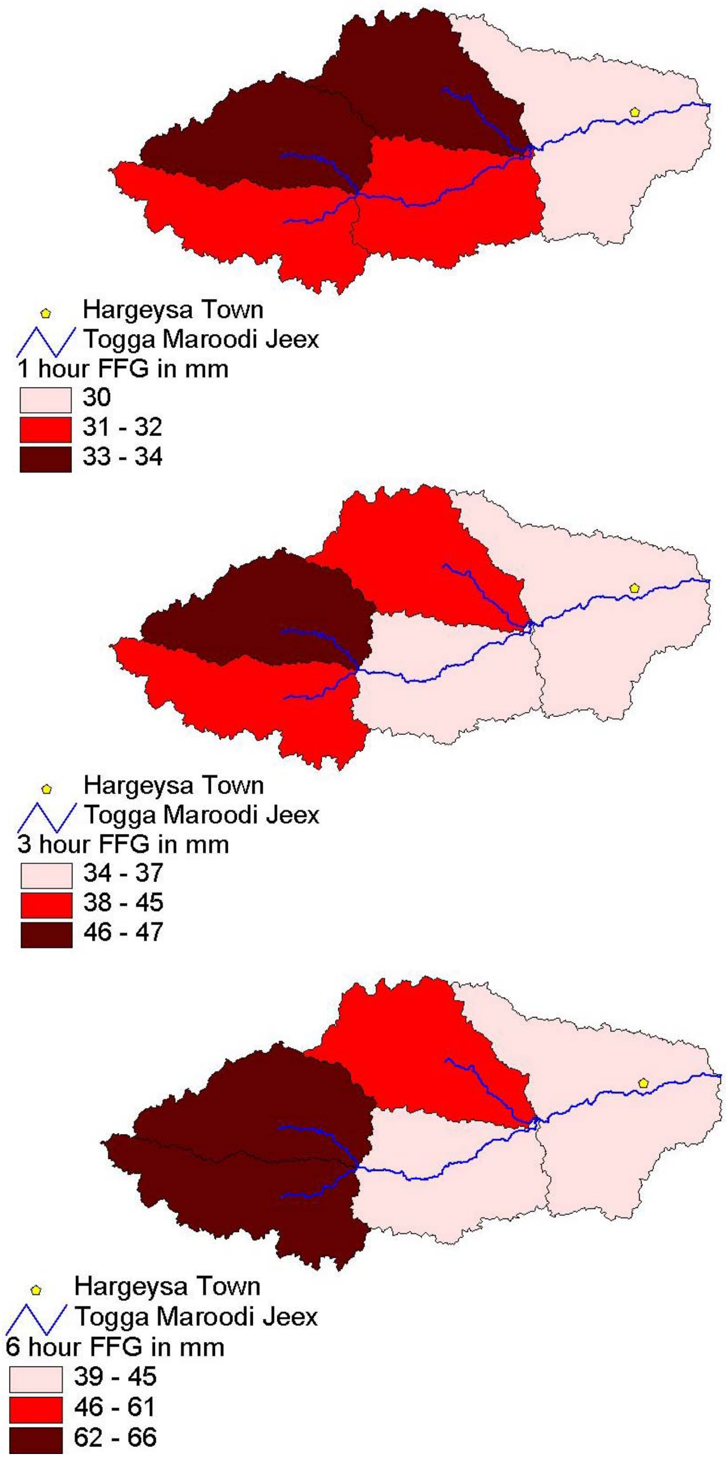


Figure 5.8b: Flash Flood Guidance values for the Togga Moroodi Jeex and tributaries for one, three, and six hours duration rainfall events

5.8 ALERT

The ALERT system will consist of precipitation and stream gage sensors depicted in Figure 5.7a-b and Infrared satellite imagery observed in real-time. The gage sensors will transmit data from the remote sites using VHF radio via mountaintop repeaters to the base stations in Hargeysa or Garowe where the data will be received and stored on computers at the base stations and transmitted daily to central computers at the Flood Forecasting Center in Nairobi for archiving. Proposed locations for the gauges and repeater stations shown in Figure 5.7a-b subject to change pending a pre-installation visit by system experts.

In each of the two basins, several automated rain gauges will be installed in the location specified in Figure 17a-b. In our opinion, data from rain gauges will not be enough to meet the accuracy needed for monitoring the atmospheric conditions that are likely to trigger a flash flood event, especially for the larger of the two basins (the Garowe basin). We suggest that the rain gauge data be augmented with METEOSAT imagery data to better follow developing severe weather events that could trigger flash floods. Such data will be useful even though the relationship between cloud-top temperature and the underlying rainfall is not well defined for the area. RFE products estimated from satellite infrared imagery have been used to monitor floods and flash floods in several settings through the world.

The Kenya Meteorological Department (KMD) receives second generation METEOSAT imagery data with temporal resolution of 15 minute and our understanding is that the KMD is not adverse in sharing such data if a memorandum-of-understanding or data sharing could be stake between them and FFC.

Flash flood ALERT will be issued whenever 10 cm of flood water is measured by the installed stream gages or the observed rainfall becomes equal or greater than the area FFG values.

5.9 Institutional Arrangements

The absence of clear strategies and policies for flood management in the region has contributed to increased adverse impacts of flash flood disasters socially, economically, and environmentally. The availability and proper use of accurate and timely meteorological and hydrologic monitoring and forecast products, and the dissemination of adequate and relevant information to authorities responsible for civil protection and to the general public for effective disaster response, all play an important part in flash flood warning and alert systems. The difficulties are compounded when the infrastructure on which to build early warning and response systems is rudimentary or nonexistent, as is the case in many developing countries in the region, including Somalia.

Setup of an automated alert system for flash floods in northern Somalia requires professional well-trained personnel for running these systems. Currently, the two administrations in the north do not have trained personnel or appropriate technology to properly warn at-risk populations of potential or occurring flash flooding in areas at risk. These systems require highly trained personnel to operate. Issuing a false alarm is very expensive in terms of evacuation and might lead to loss of credibility of forecast centres.

5.9.1 National Partners

The feasibility study evaluated roles and responsibilities of the national and international participants in the flash flood early warning system component. Several different public and private, internal and external participants have an important role in flood management in northern Somalia, especially in Somaliland. However, there are no funds available from the two administrations to support any of the water management activities in the valleys and toggas. All of the on-going or proposed efforts are based on donor support. It is not surprising that previous projects involved with flood and water resources management problems in the region by UNDP, EC, and others have failed due to lack of local contributions toward the achievement of these activities. The limited resources of the two administrations have adversely affected their involvement in flash flood early warning system and the water sector in general.

5.9.1.1 Puntland

5.9.1.1.1 Ministry of Livestock, Agriculture and Environment (MOLAE)

In Puntland, MOLAE is in charge of rain monitoring networks and rural water supply for human and animal consumption. The network of rainfall observation stations in area before the collapse of the central government in 1991 consisted of about eight stations, most of them installed after 1960. Information available from the SWALIM archive indicates that rainfall and other meteorological information and data existed for some of the stations from 1963 to 1991.

Since the collapse of the government and up to April 2007, MOLAE has never operated a rain gauge (section 5.6.2). All of the data that existed after the collapse of the central government has been collected by local and international NGOs for their monitoring purposes. The data are shared by these NGO's with SWALIM and other partners, such as FSAU and FEWS NET.

As part of its strategy, MOLAE is to obtain funds for wide area rainfall monitoring in Puntland. MOLAE submitted a proposal to the Puntland parliament for approval. The vice minister of MOLAE assured SWALIM of future collaboration with SWALIM in rainfall monitoring.

5.9.1.1.2 Puntland State Agency for Water, Energy, and Natural Resources Corporation (PSAWEN)

PSAWEN has been identified as a corporation and as the main government agency in charge of water supply in Puntland State (PSAWEN 2001[14]). The main responsibilities

[14] Water Supply Policy Green Paper – a discussion paper for review is developed jointly by UNICEF and PSAWEN. Central responsibilities are policy, development, guidelines, standards, databases collections, training, and advice on financing.

and goals of PSAWEN as stated in the Water Supply Policy Green Paper are provision of services to consumers, support for institutional development, and maintenance of service delivery.

In the paper, there is no clear role toward collection of information and data on floods and their impacts, apart from provision of technical guidance in the development of a national water plan which we assume will cover flash flood issues in Puntland. Managing drought and other water related disasters is mentioned as supplementary policy and briefing information in section E of the green paper. PSAWEN assumes responsibility to provide assistance at appropriate levels in the event of disasters related to water. More focus and emphasis is given to drought than to floods.

It is important for SWALIM to investigate further involvement of PSAWEN in the planned flash flood alert system. PSAWEN supports the ongoing process to create inter-departmental structure to take responsibility for long-term national disaster management and mitigation strategies.

5.9.1.1.3 Ministry of Public Works and Transportation (MPWT)

MPWT is in charge of all infrastructures in the state. The ministry has concerns about flash flood damage in the region. Faced with a lack of funds for rehabilitation of some of these damages, the ministry is working with many donors and partners in the region (e.g., ILO) to rehabilitate the damaged infrastructure. The Director General (DG) has been active in bringing flash flood issues to SWALIM and has shared his experience with SWALIM.

5.9.1.2 Somaliland

5.9.1.2.1 Ministry of Agriculture (MOA)

Before the civil conflict in the country, the Ministry of Agriculture had been in charge of water, meteorological, and agricultural data. Rainfall data collections lie directly under this Ministry. Under the current administration, the MOA has been working with many agencies in developing a rainfall monitoring network, e.g., German Agro-Action (GAA). Under this project the ministry was able to benefit from the hardware and data collected by GAA. Ten manual rainfall stations are operational and their data shared with the ministry and SWALIM. Two other automatic weather stations have been installed in the agricultural areas in Baki and Gabiley. Based on discussions initiated by SWALIM, GAA is planning to hand over this network to the MOA.

The MOA also hosts the FAO locust project, which developed capacity in information communication through HF radio. SWALIM visited the radio central station and agreed with the MOA on the future possibilities of using the same radio system for data transmission.

5.9.1.2.2 Ministry of Water and Mineral Resources (MWMR)

Unlike the Puntland region, the MWMR is in charge of all water resources in the Somaliland region; the Ministry of Pastoral Development supplements water needs for livestock and the nomad communities. A draft water act was developed in collaboration with UNICEF in 2004[15]. Throughout its 15 chapters and 81 articles, the act didn't mention floods, their responsibilities, or responding to impacts and provision of early warning activities.

Given the nature of the rainfall and surface water availability, there is a big gap in terms of trained hydrologists at the MWMR. Most of the trained personnel are hydro-geologists or geologists. Little or no capacity in surface water hydrology exists at the MWMR. With minimum training, skills can be improved for hydro-geologists to contribute to the planned flash flood alert activities. There is much to be done in terms of responding to floods and alerting communities at risk in floodplains. SWALIM interventions in the past two years have improved the capacity of the MWMR in terms of data archiving and processing (refer to section 5.6.2 above).

5.9.2 International Partners

5.9.2.1 Somalia Water and Land Information Management (SWALIM)

FAO SWALIM, as part of its activities over the project life span, has been working closely with the two administrations in the rehabilitation of the pre-war hydro-meteorological network. Some of the equipment has been procured and installed and the required staff has been trained in data collection and dissemination. It is envisaged that in the early stages of the establishment of such a system, SWALIM could provide the necessary capacity in terms of training of personnel from the two administrations in automatic systems data transmission, archiving, and setting the necessary thresholds for the two basins under consideration. Training in equipment troubleshooting and in the use of the software necessary for data interpretation and radio communication are also required.

SWALIM should also provide frequent backstopping to the system in terms of monitoring the hardware and software to be installed in the field and at the Ministry of Agriculture in both Somaliland and Puntland.

SWALIM has been working with MOLAE in Puntland and MOA in Somaliland in developing the necessary skills and capacity for creating an enabling environment for rainfall monitoring and data collection. So far, six people have been trained in rain gauge installation and data collection. A data center has been established at MOLAE for data collection and archiving. A central high frequency radio station for receiving data from field manual stations is planned for installation in July 2007. The station will be fitted

[15] The water act was prepared by Dr. Bernard GOLLINGON, Mr. Bill WANDERA, Mr. Cedric ESTIENNE and Dr. Albert MUMMA for HYDROCONSEIL, France. Funding and technical backstopping is provided by UNICEF.

with a data modem and fully automatic communication software for PC. Training is an integral part of the radio and communication software systems.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Key Findings and Critical Issues

Full impact of an operational state-of-the-art hydro-meteorological data collection and flood forecasting system will only be achieved if the forecasts produced by the system reach all international and local the users. For that to happen, the warning dissemination methods of the system should be adapted to the peculiar local conditions (political and social conditions in south-central Somalia vary from locale to locale) and be tailored to the needs of the potential user community. The dissemination system must be fail-safe and allow the forecasts and warnings to reach users during major flood events when there is usually a high probability of failure of the communication systems. The potential user community of system warning products will include the local authorities, flood-affected communities, and international aid organizations active in flood relief that are mostly based in Nairobi, Kenya.

For the flood forecast system to be effective, advanced planning is needed to define a set of prescribed actions that are linked to the value range of flood warning that will be issued (e.g., alert, advisory, and warning); the actions will be site specific. Typically, the public is most often concerned with water levels at specific points, mostly urban centers, whereas the output of the hydrologic model used in preparing the flood forecast will usually be in the form of discharge. To convert forecasted flows to water levels, the stage discharge relationship should be used if available. For other locales, the hydraulic model to be decided later could be used. Forecasted water levels should be given according to a geodetic datum. With the advent of global positioning systems, it is possible to provide a geodetic datum at any location. An investigation must be carried out on what kinds of data and information potential users need from the system when implemented. By sending a set of e-mails to list members of the FWG at the design stage of the flood forecasting system, we have tried to determine what sort of output the potential user community of the system would like. Up to the time of the writing of this report, we have not received any feedback from members of FWG on the kind of information they would like to see from the system. The best way to reach the user community with the warning products is also to be determined.

In the interim, until the users' preference survey is carried out, the forecast of impending river flood events will include a statement about the present conditions of the river and weather and to put into contest the hydrographs will include the long-term mean river levels for the time of the year. The forecasted water levels can be released to the public in tabular and/or graph (hydrographs) format. For the forecasted water level (in tabular or hydrograph form), it is useful to provide comparisons with the previous year's levels that shows the highest stage reached during previous major floods. Plotting forecast hydrographs in context is easy in the HYDATA environment. SWALIM staff is already familiar with this software. The forecast should be made available to international agencies involved in flood relief and related activities in Somalia, the local media outlets, community-based flood warning offices to be established, and posted on SWALIM Web sites for easy access by the public. For isolated communities that lack access to communication systems, the notification of impending flood risk will be more problematic. The best way will be to equip such communities with HF radios that are already common in Somalia.

The water level information should be translated into its impact on the area. This should be described with reference to threshold levels like “Advisory Level,” “Warning Level,” and “Historic Flood Level.” For public information, guideposts marked with these threshold levels should be displayed at prominent public places in the major settlements that are flood prone. In the future, the possibility of making an atlas with inundation maps for three warning levels for all the major settlements should be pursued. Inundation maps linked to river levels and superimposed on high resolution satellite imagery (e.g., QuickBird) will provide information on properties that could be damaged. Inundation maps would be useful for public awareness and for flood relief work.

The communities in the flood prone areas have to be educated to understand the uncertainty involved in the forecast that there is a possibility that river forecasted levels could be lower than the actual crest, and that they should remain vigilant and act quickly on receiving the warning. The forecast uncertainty should be represented as far as possible in nontechnical language that common people understand. It is vital for the forecast to be credible to avoid issuing unwarranted flood warnings based on an incomplete picture of the river system and without proper formulation of forecasts by experienced hydrologists. Unwarranted flood warnings keep people unnecessarily tense, and if such a practice is repeated a few times, people start to lose faith in the forecasting system with the consequence of not heeding flood warnings when issued.

6.2 Recommendations for River Flood Forecasting

6.2.1 Development of the Hydro-Meteorological Network

An up-to-date and reliable hydro-meteorological database is a basic prerequisite for a successful flood forecasting endeavour. We recommend the establishment of a real-time hydro-meteorological data collection network that is integrated with the hydrological/hydraulic modelling system that will be used for flood forecasting. Needed hydro-meteorological data for flood forecasting for the Somali environment are river stages and discharges, and rainfall data. Given that the flood waves in the Juba and Shabelle Rivers move slowly—on the order of days—the time delay between data acquisition and availability to the flood monitors at FFC could be as long as a day for routine periods and on the order of 3 hours during the flood season. The flood season in Somalia is about 2 months long each for the Gu and the Deyr seasons.

Implementing the proposed network should be done in phases for budgetary reasons and to allow for the adaptation of the system to the conditions of Somalia. Phasing the implementation period will be useful for the development of local expertise on equipment installation and maintenance. As early as possible within the life of the project, qualified personnel who are able to operate and maintain the network system should be sought. At first, a minimum number of stations will be built, gradually increased until the desired number of stations is in place. The network could be built in three phases; see Figure 18 for locations and installation timeframe of the proposed network.

The WMO (1965) reviewed hydro-meteorological network design strategies and stated that there were no universal standards for network design but suggested a minimum network for stream gauging stations of one station per 1,000-2,500 km^2 in flat regions (areas like the lower Juba and Shebelle basins). The network we are proposing will be quite difficult to achieve as an optimum network on a par with WMO's suggested network density standards because of the shortage of institutions and trained personnel to operate such a network in Somalia and limited financial resources that will be devoted to the task. Even a denser network than the one we are proposing will not by itself be effective to estimate basin-wide rainfall, due to the lack of shared data from the Ethiopians across the border. Rainfall is needed as input of any hydrologic model deployed. We propose that the automated rain gauge system be augmented with a satellite-based rainfall estimate (RFE) product to provide effective rainfall data for any hydrologic model deployed and for monitoring weather conditions.

The most effective way to acquire an improved RFE product over the area is to include the automated weather stations that will be part of the proposed network in the WMO GTS network data transmittal protocol.

We advise a satellite-based data transmission system, the most reliable and cost effective system for the Somali environment at the moment. The proposed data communication system will be capable of transmitting the data in the worst conditions of flooding since it will not be depended on the local telecommunication network.

In addition to flood forecasting purposes, data collected by the proposed stations could be used in the future for irrigation monitoring, modelling water availability, environmental impact studies, and infrastructure planning and design along the Juba and Shebelle.

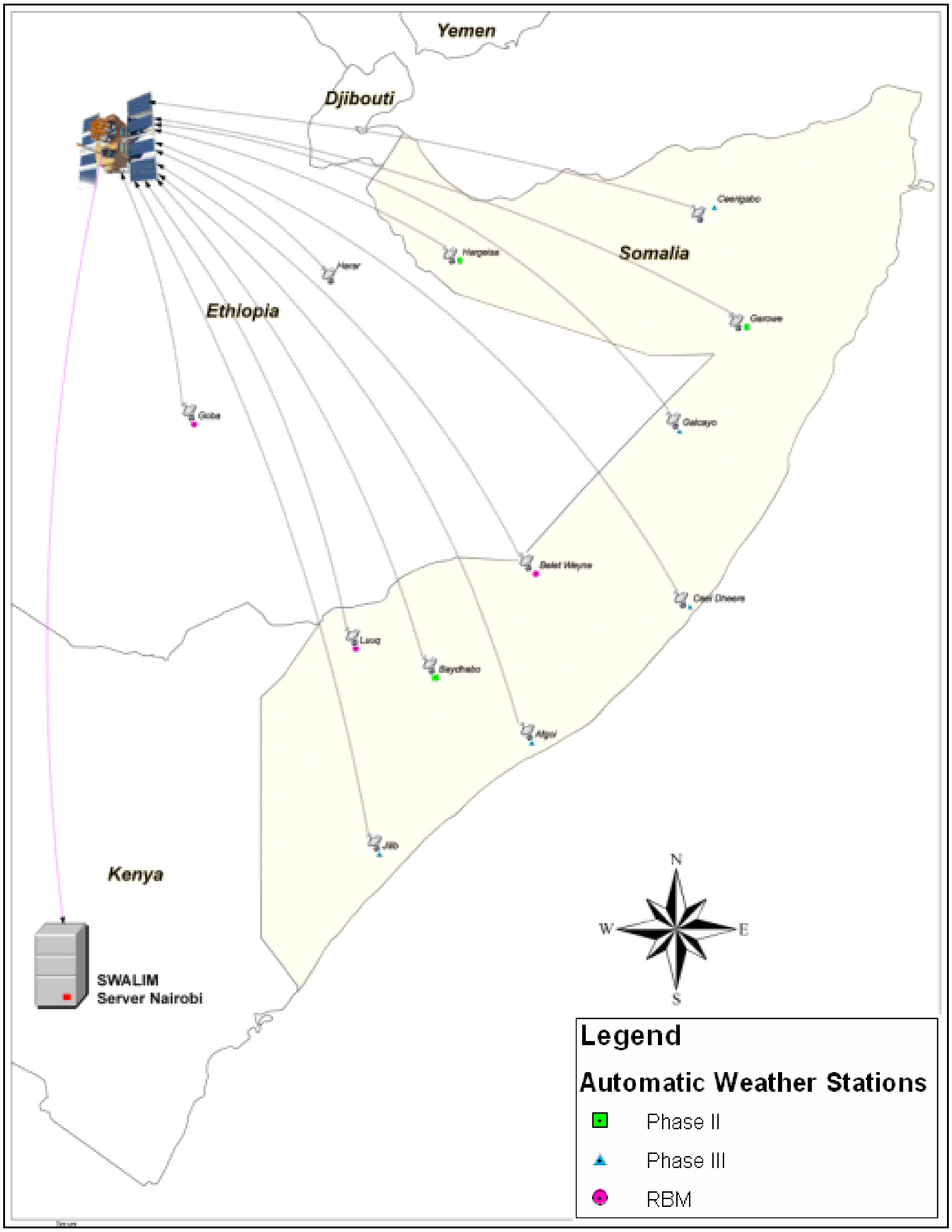


Figure 6.1: Phase installation of hydro-meteorological network

6.2.2 Data Processing and Archiving

All the data recorded by an automated hydro-meteorological network will be received by a central computer housed at the SWALIM offices in Nairobi (see Figures 6.1). The data would be stored in a database where various quality control analyses and graphical displays should be made available. The database will be linked and be accessible to the flood forecasting modelling system. Before being archived and used, the data should be scrutinized for errors; automated procedures should be used to check and eliminate gross errors. The errors could be due to the data collection instruments, the data transmission component, or, for the manually read stations, a reporting error. The most error-prone weather data are rainfall data. As part of the quality control for the rain amounts recorded by the automated rain gauge equipment, the RFE data archive (long-term data from the manually read rain gauge network stations) should be used. An evaluation of data should

1. check for the battery voltage adequacy for measurements,
2. ensure that clouds were present if observed precipitation was non-zero and,
3. ensure that the values are realistic (a "buddy check" and standard deviation check should be carried out).

The "buddy check" examines the absolute value of the difference between the current station and all stations within a two-degree grid box. If more than 50% exceeds a specified threshold, then data from the current station is eliminated. The thresholds should be specified by the centre forecasting personnel. The standard deviation check should be carried out using a girded daily climatology derived from the pre-war data in the Somalia Climatological Database and from the archive's newly established, manually read stations. The observations should be compared to the nearest grid point value from the climatology. The current observation must be within five standard deviations of the daily climatology. The RFE could be used as a "duplicate station check" and/or "buddy check" of rain gauge data to eliminate extreme values from the dataset. Some of the proposed data quality checks could be completely automated and all but some will involve a man-machine mix.

A schedule of field visits to check the status of the equipment every few months should be consistently followed. As a field visit schedule of the proposed hydro-meteorological stations, we suggest that every station should be visited and a checklist for equipment functioning followed. The visit schedule should not have more than a four-month interval. The necessity and value of routine site field visits in the maintenance of a quality hydro-meteorological data network is a practice that has been demonstrated from experience and cannot be overstated (Fiebricha, 2006).

6.2.3 River Rating Curve Development and Updating

Only by having an accurate and updated stage-discharge relationship curve is it possible to transform the routine stage-recorded data into the discharge data that are needed as input to flood forecasting models. All the rating curves that we have for the Juba and Shabelle Rivers in Somalia have not been updated since the late 1980s. Stage/discharge rating curves need updating because river stream beds and banks are not static. Because of scour or deposition of sediment, or changes in streambed and bank roughness, the stage/discharge relationship is dynamic and needs constant updating. Changes that are common during flood events are sometimes so radical they require development of a new stage/discharge rating. In the United States, USGS personnel visit every stream gauging station about 8 to 10 times a year to make direct measurements of river discharge and collect data needed to update and track changes to the rating curve for each site. Figure 19 shows the area next to the Belet Weyne gauging station. The area has been used as dumping grounds, an activity that could modify the river section's hydraulic characteristics.

Figure 6.2: Belet Weyne Gauge Site

A major weakness of the current rating curves for the Shabelle and Juba is that the points used to draw the curves were heavily weighted to the lower flows. Usually a rating curve (if properly developed) will have a break point, which is around the stage at which the river spreads out of its banks. Sometimes breaks could be at a lower stage if the river bed cross section changes dramatically, but most of the time they are at the bank full stage.

Above the bank full stage, the river does not rise as fast, given that other conditions remain constant while discharge could dramatically rise. The Shabelle River floodplains in the Belet Weyne neighbourhood are several kilometres wide, a fact that was not considered as the rating curve was being developed. The maximum recordable discharge at Belet Weyne with the pre-war rating curve is about 500-m^3/s, but actual maximum flows have been estimated to be as high as 1,400-m^3/s, Gemmel (1981).

We recommend that a new stage/discharge rating be drawn for Belet Weyne and all major river hydrometric stations. The drawing of the new rating curves should be accomplished using flows that are higher than the maximum discharges that were recordable with the old rating curve for most of the site. Given that the ADCP equipment will allow measurements of discharge to be made much faster than the traditional mechanical current meters, we advise that within a year of the program's implementation, at least 15 stage/discharge measurements at various river flow regimes be made.

As explained in 4.2.1, the Juba and Shabelle Rivers are both quite flat, a condition that would probably result in the stage-discharge relationships, especially in lower parts of the two basins, to become not single-valued (affected by hysteresis). Due to the lack of hydraulic data, we are not sure which location will exhibit a large loop in their rating curve, a condition indicating the presence of a dynamic wave, or which location will show a mild loop, an indication of a diffusion wave. For mildly looped rating curve, a one-and-one correspondence between discharge and stage could be assumed to be valid with a correction provided by the use of the Jones formula. Whether the stage–discharge relationships are affected by hysteresis or not, in the first two years while an accurate stage-discharge relationship is established for each gauging station we recommend that rating curves developed with hydraulic models based on the complete one-dimensional equations of the unsteady flow be used.

6.2.4 Flood Forecasting Model

Many public domain and proprietary models are available for use in flood forecasting. The prevailing geomorphologic conditions of the river basin, and the technical skills and experience of the available personnel at the envisaged FFC, dictated the level of sophistication of the modelling solution deemed to be the most appropriate for the Juba and Shabelle Rivers. Both rivers have poor quality archived discharge data and outdated rating curves, especially at higher flows where it matters the most.

As part of the model selection process, we conducted a preliminary evaluation of the flood forecasting skills of three models (see section 4.10) that are thought to be appropriate tools at the future FFC for their simplicity of use. The tested models were the SFFS model, LVGFM model, and a tailor-made Muskingum routing model.

We recommend that the establishment of flood forecasting modeling capabilities at FFC be done in three phases. As a first phase, we suggest the adoption of the LVGFM model as a flood forecasting tool for both the Juba and Shabelle Rivers. The LVGFM model should be calibrated with the SWALIM archived pre-war discharge data for all the pre-war hydrometric stations, and the model should be recalibrated as soon as possible when new discharge data and rating curve relationships become available.

In a second phase, we suggest the adoption of the USGS Geospatial Stream Flow Model (GeoSFM), or a similar model which makes use of remotely sensed data that can provide enhanced early warning of the inflows into Somalia from the upstream section of the two rivers in Ethiopia. Even if the Ethiopian authorities allow the installation of stream gauges along the Juba and Shabelle in their territories, there will still be a need to assess the expected river inflow between the gauges. During years of high historic floods, significant water contribution can be generated in the basin areas that are located within Somalia. Accordingly, it will not be possible to estimate complete river inflows without the deployment of a rainfall-runoff model. Given the area's lack of observed meteorological variables (such as rainfall data) that will be needed by any hydrologic model, using remotely sensed rainfall data is the only viable alternative. The NOAA RFE datasets can be used as rainfall data. Before using whatever rainfall-runoff model is adopted, it should be calibrated and validated at least for the Belet Weyne and Luuq gauging stations. Also, the rainfall-runoff model should be recalibrated annually as new discharge data become available. Recalibration of the model is needed because of the limitation of the historical hydro-meteorological data used for model calibration. Model verification and calibration should be done by using the discharge data calculated from the river stage data that were collected by SWALIM in the last few years. In the recalibration process, the development of irrigation schemes and barrages in the upstream sections of the basins in Ethiopia should all be considered. If not accounted for, these changes can quickly make the deployed model obsolete.

In the third phase, for the river sections downstream of Belet Weyne for the Shabelle and Luq for the Juba we recommend the implementation of full hydrodynamic model aided by the rainfall-runoff and the LVGFM models. For the hydrodynamic model we suggest that it be selected from the US National Weather Service Flood Wave Routing Model (FLDWAV) described by Fread and Lewis (1988), the HEC-RAS (River Analysis System), and the hydrodynamic module of MIKE 11 model of Danish Hydrologic Institute (DHI). HEC-RAS has a GIS data interface that allows data inputs for stream topology and cross-sectional shape, whereas MIKE 11 has an Arc View-based GIS interface. The FLDWAV model is the best hydrodynamic model but it lacks a GIS interface and therefore will need the most tailoring for the Somali conditions. Selection of the appropriate hydrodynamic model should be reached after a tender is offered and costs are evaluated. Irrespective of hydrodynamic model adopted, there will be a need to adapt the model to the hydraulic conditions of the Shabelle and Juba Rivers. In addition, emphasis should be given to proper calibration of the model as good quality stage-discharge data become available.

All hydrodynamic models will require/need hydraulic and flow roughness data to be collected, e.g., data such as hydraulic, structures, and roughness. The geometric data are channel reach length, and channel cross-section. The structure data are the hydraulic characteristics of features on the river, such as bridges, barrages, levees, and flood relief channels that must be coded into the model. Data on roughness at each point along the river as well as across the channel are needed. The most costly data to collect would be river cross-sections. By using remotely sensed data, field surveys of channel cross-sections could be minimized without resulting in an excessive cross-sectional spacing in the model. Usually, cross-sectional spacing becomes excessive if the slope of the energy grade line decreases by more than 50%, or increases by more than 100%; then the reach length is too long for accurate determination of the energy loss. The most uncertain parameter to estimate is the value of the roughness coefficient. Roughness parameter can be estimated from the flow and cross-section data collected with the ADCPs.

An updating procedure, which utilizes measured water levels to minimize differences between observations and simulation at the time of forecast, should be implemented. We suggest that an autoregressive updating model be adopted because of the simplicity and robustness of such models.

The task of developing forecasting models will be carried out preferably by a consulting hydrologist with knowledge of GIS and remote sensing applications in hydrology. For a comprehensive model modification, calibration and validation, and technology transfer to be accomplished the duration of consultancy should not be less than 12 months. Technology transfer to the FFC is required because it is necessary to have a continuing cycle of model calibration, collection of river-discharge and rainfall data, and model recalibration to provide a model that is a current and useful. Such model recalibration and revalidation a job should be done by the staff of the FFC that has been train by the consulting hydrologist.

6.2.5 Establishment of a Flood Forecasting and Warning Centre

We advise the establishment of a Flood Forecasting Centre (FFC), where flood forecast messages will be formulated and disseminated to the stakeholders. For logistical reasons, the FFC should be first based at Nairobi, and the centre run by a professional staff hired and managed by the SWALIM project or a comparable technically competent organization. The FFC will possess

1. access to up-to-date quantitative precipitation forecasts and satellite estimates of rainfall,
2. details on the channel geometry and structures on the river
3. real-time access to the data collected by the hydrometric and weather stations network that will be installed in the Juba and Shabelle basins,
4. An operational flood forecasting system capable of forecasting river flow at locations and of forecasting horizon times of up to seven days,
5. an operations manual to assist in deciding the course of action when a flood warning is issued,
6. a flood warning dissemination system and network, and
7. a procedure for evaluating forecasting system performance after the flood.

During periods of flooding, the FFC will issue flood forecasts for the expected height of the flood crest. In routine operations, river flow forecasts should be computed once a day for up to seven days into the future. During the flood season, forecasts should be issued daily, and during the course of a severe flood event, forecasts should be run twice a day. Figure 20 illustrates the data and information flow from the data acquisition to the flood forecast issuance.

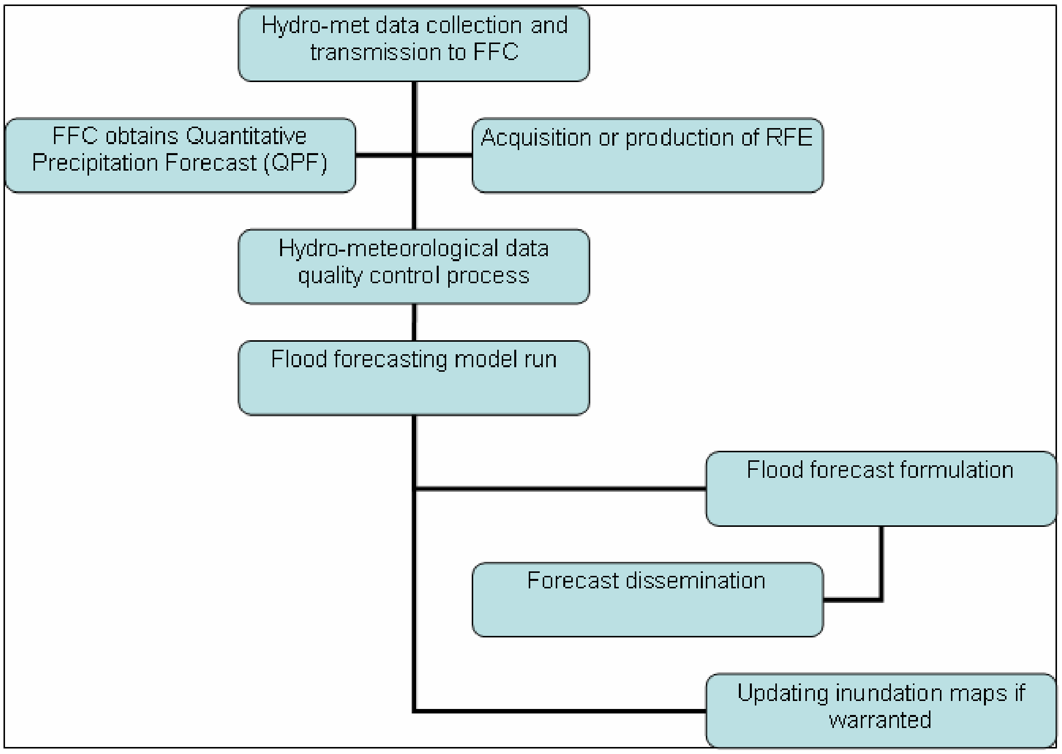


Figure 6.3: Diagram of the data flow between the field, partner organizations, the FFC, and the end user of the forecast product

We envisage that the minimum staffing level needed by the centre to be one hydrologist modeller, one data analyst, one system administrator, and required supporting secretarial staff. To reduce the operational cost of the centre, staff and office spaces could be shared with other projects.

The FFC will be a national institution. There will be a need to downscale and follow up the forecast; to that end, we suggest the creation of two Regional Flood Forecast Centres (RFFCs) in the two basins. The RFFCs will be responsible for the established of Community Flood Management Committees (CFMC) at village levels. The RFFC could be created and managed by the Somali authorities with external help. The two RFFC roles will be to:

1. assist in community education and awareness programs,
2. keep the FFC informed on the status of river embankments and flood relief channels,
3. disseminate flood forecasts and warnings issued by the FFC to the local communities,
4. to assist in community flood preparedness

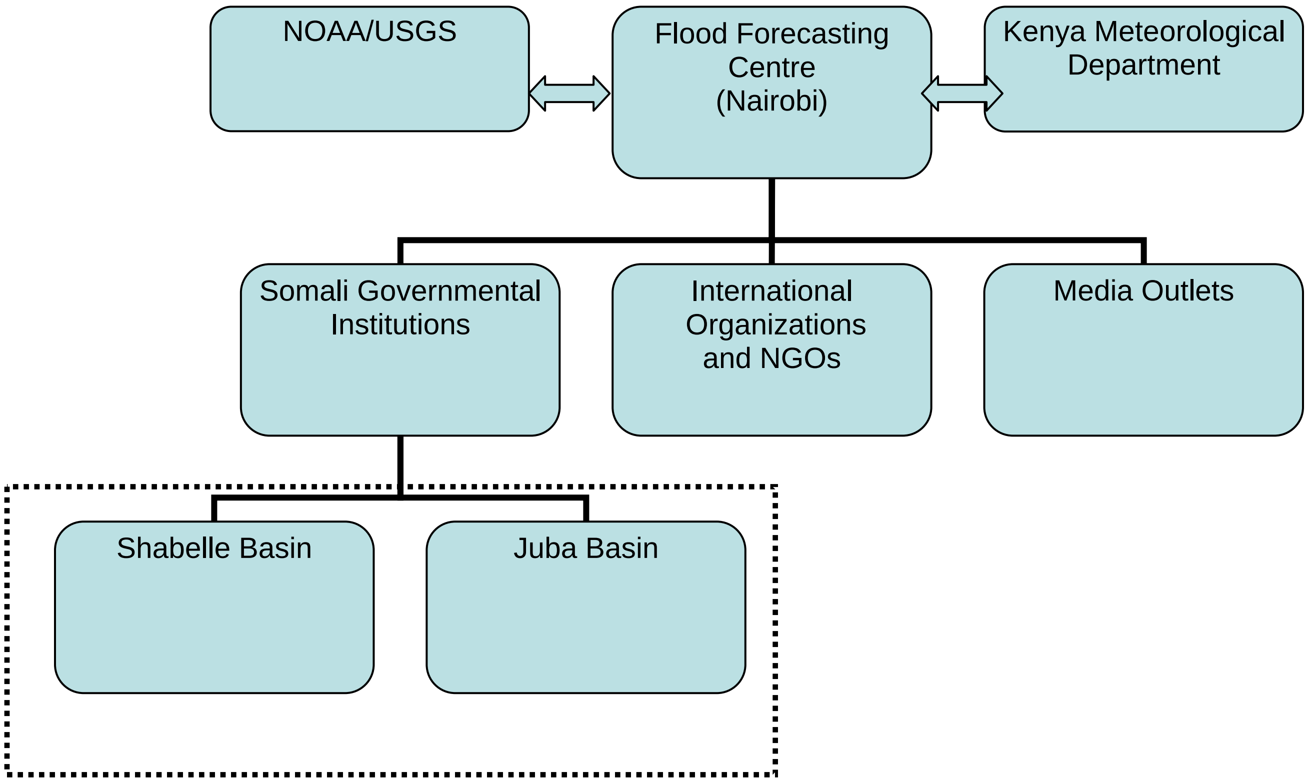


Figure 6.4: Envisaged institutional arrangement for the river Flood Forecasting Centre (FFC)

Figure 6.5 outlines the respective area of responsibilities of the National FFC and locale FFCs (if they are established) for the flood forecast formulation and for the dissemination of warning messages.

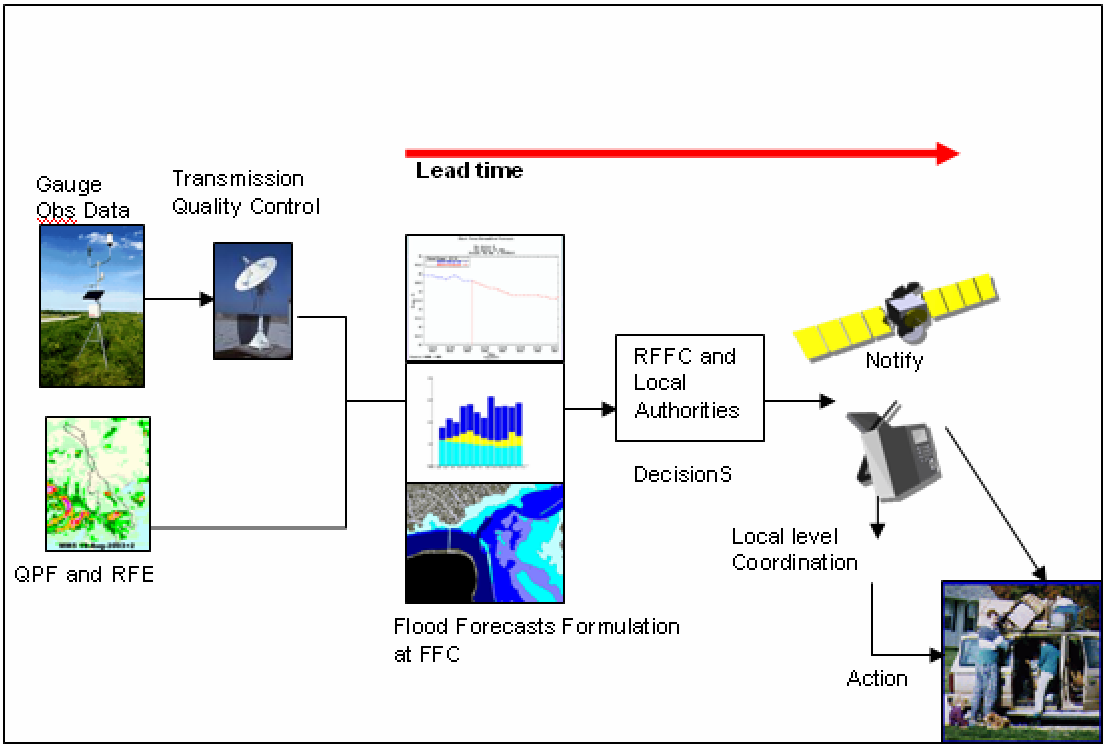


Figure 6.5: Data, information, actions flows from the detection of a flood onset to issuing and dissemination of flood warning

6.2.6 Flood Forecast Warning Message

Flood warning messages should include the date and time when the river is expected to overflow its banks, and the date and time when the flow in the river is expected to recede to within its banks if such date is within the forecast time horizon. The forecasts should be updated as new weather and hydrometric data are acquired. As the new data become available, the data will be entered into the hydrologic/hydraulic modelling component of the flood forecast system, and new river forecasts will be produced. The flood forecasting model will be connected with the hydro-meteorological database that is interfaced with the real-time telemetry system. The flood forecast warning product should include current and forecast river level conditions at the forecast location. Flood warnings for all the forecast locations should include

1. a statement and graph of the current and expected river stage levels above a certain datum,
2. a summary of the regional rainfall conditions, including the forecast and the latest available observations from the weather stations that are located in the basin, and
3. an interpreted message about the predicted height of river stage level.

Ultimately, the forecast should include an interpretation of forecasted river levels into depths and areas of likely inundation.

6.2.7 Community Education and Awareness

Community education on reducing flood hazards for flood prone areas should be initiated as early as possible in the implementation period. Educating communities at risk on the meaning and action required when a flood *advisory* or *warning* is issued is an important component of the success of the forecasting system. Because people learn of a flood threat as a member of a group, their response to an impending flood threat is to a great extent influenced by how the group heeds the warning.

When a flood *advisory* is issued for an area, the population in the low-lying areas should be educated to listen to the radio (or television) or to be in established local community-based forecast centers for updates on floods for the duration of a flood emergency event. The communities should be made aware of the need to be ready to act quickly when a flood *warning* is issued. The flood forecasting and warning systems, an atlas that contains flood hazard maps, and evacuation planning need to be closely linked in the river basin.

Public awareness and education are critical; education ensures that people at risk and those who assist them will know in advance what to do during a flood emergency. For example, flood warnings issued with sufficient lead-time will allow the communities at risk (especially the communities along the lower Shabelle) to temporarily flood-proof manmade breaches of the river embankments that are more likely to cause flooding.

6.2.8 Flood Inundation Maps

As part of improving flood forecasting and early warning in Somalia there is a need to create flood inundation maps of all major towns that are situated in flood-prone areas. With flood inundation maps, local authorities and communities at risk could better plan their land use, and develop procedures on the evacuation of the people that live in the flood-prone areas. Flood hazard inundation maps could also be used in conjunction with the proposed network of real-time river level monitoring to help future relief efforts of flood-affected populations in the area.

6.3 Expected Uncertainties and System Sustainability

WMO (1996) introduced a point-rating system called “Management Overview of Flood Forecasting System (MOFFS).” MOFFS provides a consistent (although not objective) method to evaluate the performance of flood forecasting systems. After every flood season, the flood forecasting model’s real-time operational performance should be evaluated, using QPF as model input during post-flood evaluation. The inability of the flood forecast model to generate accurate stream flow forecasts could be due to model parameter uncertainty, model structural error, input uncertainties, and observed stream flow measurement errors. Uncertainty due to parameter uncertainty and model structural error should be quantified before the deployment of the model and reduced with the updating of the model. *Overall uncertainty should not be higher than 10%.*

6.4 Hardware, Software and Resources Estimates

Annex 2 gives a list of the hydrometeorological hardware that we are proposing for the river flood forecasting system (for the Juba and Shabelle Rivers) and the flash flood alert system for Garowe and Hargeysa towns. Beside the hardware and software costs, a major cost that to should be included in the planning of establishing the hydrometeorological network system is the long-term costs for maintenance and operation of the systems.

Costs associated with the consulting needs for the establishing of the hydrologic modeling capabilities at the FFC are estimated to about 15 months/man. Time that will be dived between consulting needed for development of the hydrologic/hydraulic models for the Juba Shabelle basins and the development of flash flood guidance’s values. Hydraulic data needed for model development should be collected by SWALIM project field personnel.

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Annexes

Annex 1: Existing Network of Rain Gauge Stations

	Rainfall Station	Region	District	Agency Responsible
1	Garoowe	Nugaal	Garoowe	FSAU
2	Xasbahale	Nugaal	Garoowe	FSAU
3	Halgan	Hiran	Bulo Burti	FSAU
4	Jalalaqsi	Hiran	Jalalaqsi	FSAU
5	Afgooye	Shabelle	Afgooye	FSAU
6	Genale	L. Shabelle	Marka	FSAU
7	Bardaale	Bay	Dinsor	FSAU
8	Diinsor	Bay	Bardale	FSAU
9	Huduur	Bakool	Hudur	FSAU
10	Ceel Berde	Bakool	Ceel Berde	FSAU
11	Sakow	Middle Juba	sakow	FSAU
12	Jamame	L. Juba	Jamame	FSAU
13	Baidoa	Bay	Bay	FEWSNET
14	Belet weyne	Hiran	Belet Weyne	SCF
15	Bulo burti	Hiran	Bulo Burti	SWALIM
16	Luuq	Gedo	Luuq	CARE
17	Bardheere	Gedo	Bardera	CARE
18	Waajid_ACF	Bakool	Wajid	ACF
19	Garowe_ADRA	Nugal	Garoowe	ADRA
20	Huddur_ADRA	bakool	Huddur	ADRA
21	Baki	Awdal	Baki	GAA
22	Bonn	Awdal	Boroma	GAA
23	Boroma_GAA	Awdal	Boroma	GAA
24	Dilla	Awdal	Baki	GAA
25	Garba raho	Awdal		GAA
26	Gargara	Awdal	Boroma	GAA
27	Harmata	Awdal	Baki	GAA
28	Horey	Awdal	Baki	GAA
29	Adad	Awdal	Boroma	GAA
30	Heego	Awdal	Boroma	GAA
31	Tiaglow	Bay	Tieglo	WVI
32	Sakoow_WV	Bay	Dinsor	WVI
33	Bualle	Bay	Bualle	WVI
34	Salagle	L.Juba	jilib	WVI
35	Wajid_WV	Bakool	Wajid	WVI
37	Boroma_coopi	Awdal	Boroma	COOPI
38	Hargeisa_coopi	W. Galbeed	Hargeisa	COOPI
39	Jowhar	M. Juba	Jowhar	CEFA

	Rainfall Station	Region	District	Agency Responsible
40	Mataban	Hiraan	Belet Weyne	SCF
41	Yibir Suge	Hiraan	Belet Weyne	SCF
42	Kerialo	Hiraan	Bulo Burti	SCF
43	Agsibiri	Hiraan	Belet Weyne	SCF
44	Hargeisa_MOA	Galbeed	Hargeisa	MOA
45	Gabiley_MOA	Galbeed	Gebilley	MOA
46	Aburin	Galbeed	Aburin	MOA
47	Dila	Awdal	Dila	MOA
48	Borama_MOA	Awdal	Borama	MOA
49	Hariirad	Awdal	Hariirad	MOA
50	Berbera	Sahil	Berbera	MOA
51	Sheikh	Sahil	Sheikh	MOA
52	Odweyne	Tog dheer	Odweyne	MOA
53	Burao	Togdheer	Burao	MOA
54	Caynabo	Sool	Caynabo	MOA
55	Hudun	Sool	Hudun	MOA
56	Ceel Afweyn	Sanaag	Ceel Afweyn	MOA
57	Ceerigaabo	Sanaag	Ceerigaabo	MOA
58	Las anod	Sool	Las anod	MOLAE
59	Qardo	Bari	Qardo	MOLAE
60	Bossasso	Bari	Bossasso	MOLAE
61	Galkayo	Mudug	Galkayo	MOLAE
62	Badhan	Sanag	Badhan	MOLAE

Annex 2: Proposed hardware for the hydrometeorological network

Station	Type	Area	Region	Parameters	Telemetry	Base Station
Dhaboolaq	Rain	Hargeisa	Somaliland	R	Radio	Hargeisa
Xareed	Rain	Hargeisa	Somaliland	R+ water (1)	Radio	Hargeisa
Malowle	Rain	Hargeisa	Somaliland	R	Radio	Hargeisa
Xaraf	Rain	Hargeisa	Somaliland	R	Radio	Hargeisa
Hargeysa	Rain	Hargeisa	Somaliland	R	Radio	Hargeisa
Elkodan	Rain	Garowe	Puntland	R	Radio	Garowe
Duss	Rain	Garowe	Puntland	R	Radio	Garowe
Rabaable	Rain	Garowe	Puntland	R+water (1)	Radio	Garowe
Lugo	Rain	Garowe	Puntland	R	Radio	Garowe
Garowe	Rain	Garowe	Puntland	R	Radio	Garowe
Hargeysa	Radio telemetry	Hargeysa	Somaliland		base station & repeaters	
Garowe	Radio telemetry	Garowe	Puntland		base station & repeaters	
	Rain	BACKUP				
	Rain	BACKUP				
Hargeisa	AWS	Hargeisa	Somaliland	T,RH,SR, Ws,Wd, Ts, Ap, R	Iridium sat	Nairobi
Garoowe	AWS	Garowe	Puntland	T,RH,SR, Ws,Wd, Ts, Ap, R	Iridium sat	Nairobi
Baidoa	AWS	Central & South Somalia	Central & South Somalia	T,RH,SR, Ws,Wd, Ts, Ap, R	Iridium sat	Nairobi
	AWS	BACKUP				
Luuq	Hydr	Juba	Central & South Somalia	R, WI	Iridium sat	Nairobi
Bardheere	Hydr	Juba	Central & South Somalia	R, W I	Iridium sat	Nairobi
Belet Weyne	Hydr	Shabelle	Central & South Somalia	R, WI	Iridium sat	Nairobi
Bulo Burti	Hydr	Shabelle	Central & South Somalia	R, WI	Iridium sat	Nairobi
Base Station SWALIM					Iridium	
ADCP		Juba				Luuq
ADCP		Shabelle				Belet Weyne