SOM/SSF/2001/12
Working Paper

A SYNTHESIS
OF
FLOOD WARNING AND CONTROL
FOR THE
JUBA AND SHABELLE RIVERS

JUNE 2001

FAO SOMALIA

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Executive Summary

This paper is a synthesis of relevant projects in the area of flood early warning and control. It identifies opportunities for carrying the work forward in Somalia. Recognising the operational constraints of managing flood on two major rivers in a national context of complex emergency, the paper presents recommendations to bring the monitoring and response of flood on the Juba and Shabelle rivers into line with "best international practise" in flood event.

Recognising that floods usually cause more loss of human life and greater economic loss world wide per year than any other natural disaster, and that the El-Nino event of 1997/8 in Somalia has catalysed a rethinking of flood management of the Juba and Shabelle, the paper concurs with international water resources thinking that:

- The effective means to reduce the death toll caused by floods are **advance warning** and **evacuation**,

and that

- The effective means to substantially reduce the loss and damage to people, property and environment caused by floods are **advance warning and flood control**.

In this working paper the hydrology of the rivers is first presented based on analysis of time series data derived from the Hydrometric Databook of Somalia 1951 – 1989. The analysis shows that some general similarities between the rivers exist, in terms of catchment characteristics and the extensive influence of Ethiopian flow, upstream within-Somalia-reach geomorphology, and the normally bi-modal nature of annual flows. However, there is significant differentiation between the rivers in terms of flow and flood discharges, the inter-annual variability of flood flows, and the downstream drainage geomorphology.

Annual mean and maximum mean flows are presented and return period flood peaks for Luuq (Juba) and Belet Weyne (Shabelle) derived. Between river and within river correlations are also calculated and presented. It is also demonstrated that because the catchment of the Juba river is more complex, the flood flow is both much greater and more variable than the Shabelle. On the other hand the Shabelle basin, although more "*reliable*" for irrigation in the flood plains, is more "*vulnerable*" to less extreme flood events than the Juba basin. This is because downstream Shabelle flow is often bank full, because of the influence of the poor regional management of the various flood control structures, and partly as a result of flow correlations decreasing significantly as the river nears its end.

Basic data, the characteristics of both rivers, and of the pre-war gauging sites are offered to support the hydrologic analysis. In addition three types of river modelling; a regional flood risk model, a flow forecasting model and a small scale hydraulic flood routing model are presented; and their potential role and usefulness in flood management outlined.

This paper recognises that there is a basic mechanism within the SACB for managing flood but that there is room for improvement. This relies on professionally directed competence in river hydrology and flood, as an input to a more or less permanently established flood management group. Major stakeholders in the proposed flood group are set out, matching the optimal international competence to the needs and abilities of community based organisations and governing institutions in Somalia.

In this working paper current water resources thinking in flood control and flood warning are presented and examined in some detail.

It is noted that **flood control** for large rivers can be accomplished through an integrated approach including:

- **Non-Structural measures** - Flood forecasting, flood warning, evacuation, letting rivers flood naturally, etc.

- **Structural measures** - Storage reservoirs, levees and dykes, flood diversion, sediment control, maintenance (clearing) of watercourses, etc.

and that a combination of these measures has been tried in the Juba and Shabelle basins in the past. However most schemes have fallen into disrepair during the civil war so effective flood control is currently limited. In this case further study is recommended for FAO to develop an overview of the rivers, and to identify priority schemes for rehabilitation. A bibliography of water resource management schemes for both rivers is annexed as a starting reference.

In terms of **flood warning**, it is noted that that greatest benefit accrues from adequate technical advice and community preparedness in advance of floods linked to the establishment of a flood warning system. As was concluded from the Somalia flood experience of 1997/8, it is argued that the importance of the advance preparation cannot be over emphasised. This is because the time scale of floods is too short to permit the development of an action plan, deployment of equipment, and establishment of communication channels after the flood threat becomes evident.

A generic early warning system that any large river requires is defined. It includes;

- **Forecast procedures**
- **Rainfall and streamflow observation**
- **Rapid, reliable communication systems with emergency backup**
- **Flood warning co-ordination**
- **A warning dissemination plan**
- **Preparedness planning**

and the paper examines the current situation in Somalia, and amongst the SACB, with respect to it. Two critical factors are noted in that;

1. **There is a critical link between warning and preparedness.** ie. There is little point in a forecasting and warning service providing timely and accurate flood prediction if these do not elicit the appropriate public response. As floods require the response to be more or less immediate, emphasis must be given to the organisational and sociological aspects of flood warning and control programming, and to public education.

2. **A mechanism needs to be established for the issuing of a graded flood warning.** ie. Flood warning needs to based on a scientific understanding of the river flood characteristics tied to a graded warning-level state. This is because without some *measure* of flood risk it is not clear at what level the situation passes from normal (*green*) to alert (*amber*) to danger (*red*). For any flood event it therefore has to be defined exactly what measure of flood risk there is, who is mandated to issue a flood warning, how it should be issued, and to whom it should be sent.

Finally, to address the improvements identified for improved flood management of the Juba and Shabelle rivers a set of three recommendations are offered. These are:

1. The setting out of a minimum "best practise" operational standard in flood warning, and lobbying for its adoption by the SACB as soon as practical. In general terms the most critical components of operations must include:

i. The establishment of a Flood Management Group that brings together the required expertise under a permanent flood co-ordinator for both rivers.

ii. Ensuring the penetration and flow of key data, and in good time.

iii. Simplification of communications processes; minimising transmission time and routing through a clear chain of command.

iv. The establishment of a graded system for flood warning, to be issued only by the flood co-ordinator.

v. Linking the warning to effective community flood planning and response.

2. FAO to continue development of a program in flood, taking account of its comparative advantage in information systems, and its mandate (within the UN system) for creating an overview of the Juba and Shabelle rivers.

To this end synergies and opportunities for FAO are examined in relation to the ongoing FSAU and AFRICOVER projects. A recommendation is then made for within FAO programming to merge various aspects of the livelihoods based approach of FSAU, and the environmental resources based approach of AFRICOVER, within a water and land information system.

Further inter-agency programming is also recommended to ensure the critical link between flood warning and preparedness at the local community level is achieved. It is recognised that local community work is best achieved through international or Somali NGOs with a long-term presence within Somalia. In terms of technical assistance to support the community based initiatives as much as possible, a further study is advised as a basis for developing an overview. The aims are to;

i. Collate and disseminate an inventory of flood control projects completed, ongoing or planned since the El-Nino floods of 1997/98 (since the El-Nino event wiped out much of the previous work pre 97/98 work is probably not relevant).

ii. Collect and assess the available historic studies in flood control, irrigation and drainage. Determine the importance of the various projects for flood control through technical and engineering analysis.

iii. Collate and disseminate an inventory of flood control infrastructure that is currently non-functional, and which, by being non-functional, increases the risk of major flood events and/or the vulnerability of local communities to it.

iv. Determine flood risk zones in the riverine areas. Determine priorities for strategic rehabilitation of infrastructure based on its importance for flood control and the ability of local communities to operate and maintain it.

3. To develop a project in water and land management information systems for Somalia. In fact, FAO are currently mandated to develop this project by the SACB WSIS committee and the Agricultural Working Group of the SACB FSRD committee. With support funding by UNDP Somalia to develop an FAO executed project pending, this recommendation is likely to be realised.

1. Objective

The aim of this paper is to produce a synthesis of relevant projects in the area of flood early warning and control, and to identify opportunities for carrying the work forward.

It should be recognised that floods usually cause more loss of human life and greater economic loss world wide per year than any other natural disaster. The effective means to reduce the death toll caused by floods are advance warning and evacuation. The effective means to substantially reduce the loss and damage to people, property and environment caused by floods are advance warning and flood control.

2. River Flow and Flood

Fig 1 shows that both rivers originate in the Ethiopian highlands, the main contributing catchments being fairly close together. The area of the Juba basin is approximately 223,000 km^2 and the Shabelle 307,000 km^2. Although the Shabelle is technically a tributary of the Juba it is very rarely that flow from the Shabelle ever reaches the Juba. It is widely assumed that well over 90% of the mean annual flow of both rivers in Somalia originates outside the country (Kammer-FAO 1990).

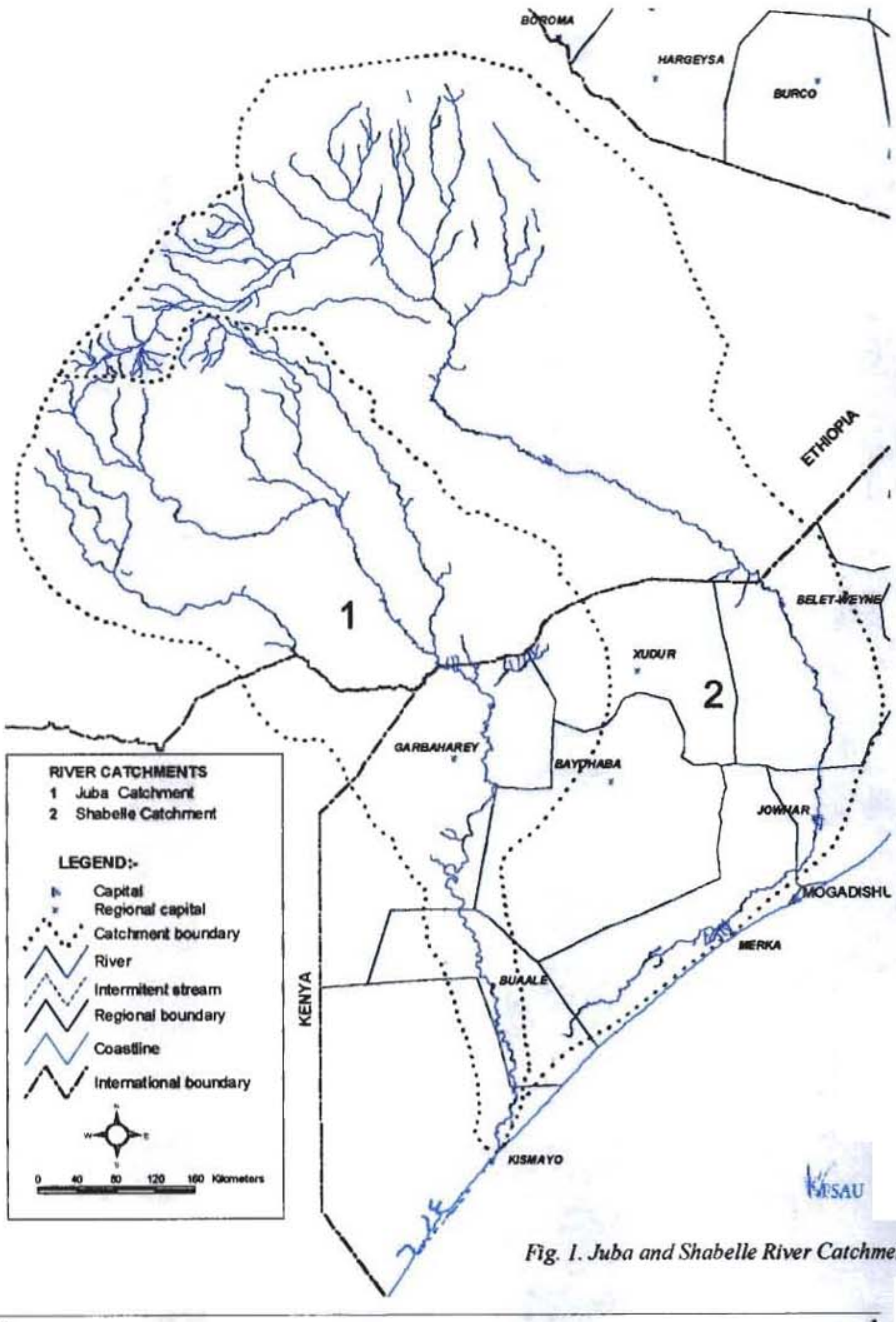


Fig. 1. Juba and Shabelle River Catchments

Normal flow is bi-modal for both rivers with extended low flows at the start of the year followed by two flood peaks: the *Gu* (April-May) and *Deyr* (September-November). Figure 2 shows the mean annual flow for the upstream towns of Luuq (Juba) and Belet Weyne (Shabelle). Table 1 summarises flow characteristics. Annex B provides notes additional information, including on the source of data used.

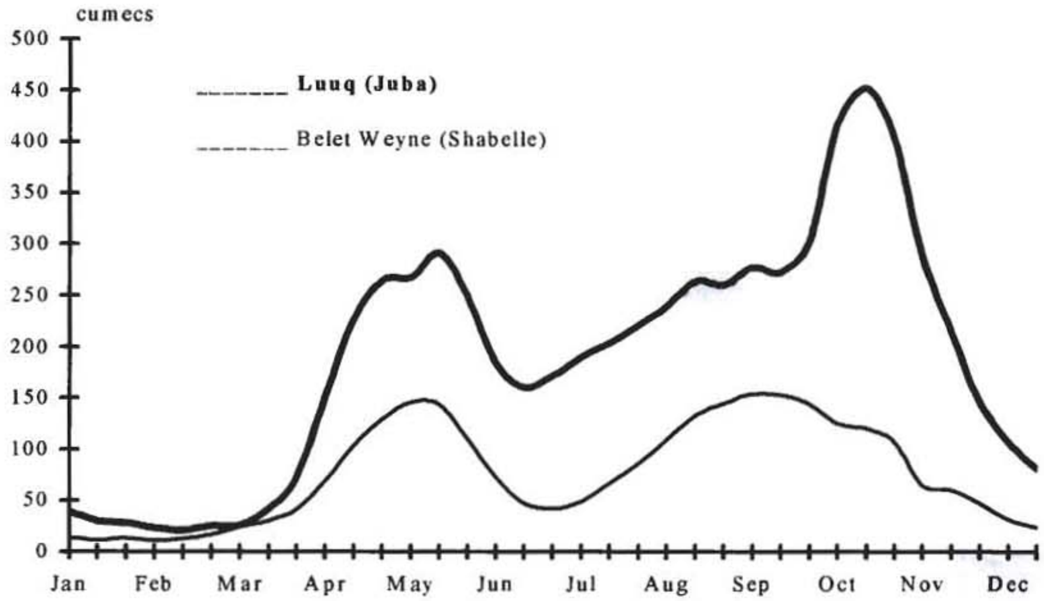


Fig. 2. Mean Annual Flow - Upstream Juba and Shabelle

	Luuq	Belet Weyne	units
Annual Mean Flow	**187**	**74**	cumecs
Annual Maximum Mean Flow	**817**	**256**	cumecs
Annual Mean Discharge	**5.9**	**2.3**	km^3

Table 1. Annual mean and maximum mean flows for Luuq (Juba) and Belet Weyne (Shabelle)

Analysis of time series (DfID/Somali Ministry of Agriculture 1990) shows the correlation between mean flows is strong ($\rho = 0.89$) but the correlation between maximum flows is much less significant ($\rho = 0.6429$). To understand why it is worth noting that the inter-annual coefficient of variation of mean flows at both Luuq and BeletWeyne are similar ($\sigma = 31$ and 32% resp.), however, the difference in inter-annual variation in maximum flows is marked ($\sigma = 46$ and 35% resp.). Put simply, although major flood events often occur on both rivers in the same year it is not always the case, so care must be exercised in differentiating the contribution of the Ethiopian catchments to flood on either river. In fact, the catchment of the Juba is more complex and flood flow is more variable than the Shabelle, which is consequently the more *predictable* river in the upstream Somali reaches (see also Annex B).

Rtn period	% exceedance	Luuq	Belet Weyne
1.01	**99**	**230**	**110**
1.05	**95**	**350**	**140**
1.25	**80**	**530**	**190**
2	**50**	**760**	**250**
5	**20**	**1100**	**320**
10	**10**	**1300**	**380**
20	**5**	**1500**	**430**
50	**2**	**1700**	**490**
100	**1**	**1900**	**540**
1000	**0.1**	**2600**	**700**

Table 2. Return period flood peaks in cumecs for Luuq (Juba) and Belet Weyne (Shabelle)

By fitting a Gumbel type 1 distribution to the available data, the estimated flood peaks (expressed in daily mean flow in cumecs) for various return periods have been derived (see table 2).

The two rivers differ substantially in the way the flows change between upstream and downstream reaches, and the inter-riverine relation between downstream flood flows is very weak. In both rivers there is some natural attenuation of floods, but whereas most of the Juba flow reaches the sea none of the Shabelle does so.

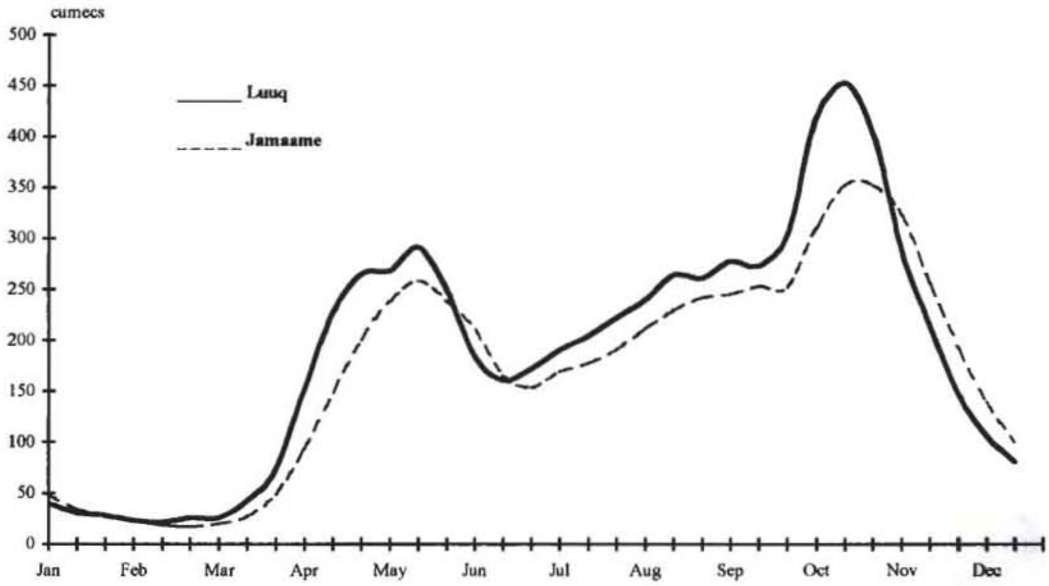


Fig. 3. Annual Mean Flow - Juba: Luuq and Jamaame

For the Juba, figure 3 shows that the reduction in annual mean flow between Luuq (187 cumecs) and Jamaame (170 cumecs) is small over the 740 km bed reach, and so the correlation is very strong ($\rho = 0.95$). There is usually some increase between Luuq and Bardera from occasional storm run-off, but this is cancelled out by abstractions and losses before Jamaame. However, correlation between daily flood peaks is much less significant ($\rho = 0.63$). This is because for short periods the Juba experiences bank-full conditions in its lower reaches, with the river capacity at Jamaame (480 cumecs) unable to absorb the full impact of flood waves. Structural measures along the banks; flood protection bunds alternating with flood diversion and irrigation schemes, have in the past formed the basis of managing the lower Juba's annual high flows.

On the Shabelle the flow usually ends in swamp beyond Sablale. Even so the reduction in flow between Belet Weyne and the pre-swamp reaches is highly marked. Figure 4 shows that the reduction in annual mean flow between Belet Weyne (74cumecs) and Audegle (45 cumecs) is significant over the 625km bed reach, and so the correlation is not strong ($\rho = 0.8$). This reduction is because the bank full capacity in the lower Shabelle is much lower than in Belet Weyne, and it is usual for the river to stay at or close to bank full for a considerable period of the flood season. Maximum flows between Belet Weyne and Audegle also show a very weak correlation ($\rho = 0.24$). This is mainly because downstream the low channel capacity causes so much over-bank spillage, and abstraction rates are very high.

In fact, it should be recognised that a significantly larger area of downstream Shabelle than the Juba is flood irrigated, precisely because flood is more "*reliable*" there. The majority flood plain of the lower Shabelle is south of Audegle, flood irrigation is extremely widespread and consequently the impact of flood events is strongly felt there. But flood irrigation requires effective, co-ordinated management of flood control structures along the river reaches, and in the current situation this cannot be assured. This in turn makes the Shabelle *more* vulnerable to *less* extreme events. A typical case is 1990: there was extensive flooding in the Middle and Lower Shabelle from an extreme Gu flood, even though annual

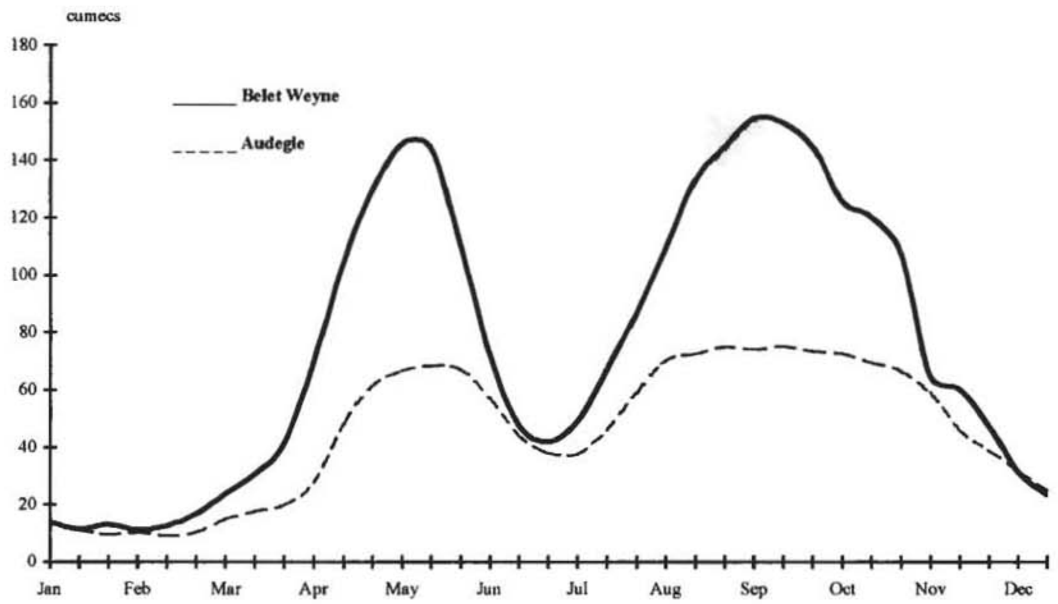


Fig. 4. Annual Mean Flow - Shabelle: Belet Weyne and Audegle

flow magnitudes were not unusually high, the flow rate through Belet Weyne averaged at a two year return period flow (Van Urk-UNDP 1990). As with the Juba a wide range of structural measures have been employed to control flood in the past.

3. Flood Control

World wide experience (Braga and Watt-UNESCO 1998) has shown that flood control for large rivers can be accomplished through an integrated approach including:

- **Non-Structural measures**
  - Flood forecasting, flood warning, evacuation, letting rivers flood naturally, etc.

- **Structural measures**
  - Storage reservoirs, levees and dykes, flood diversion, sediment control, maintenance (clearing) of watercourses, etc.

At a smaller scale measures for effective flood control include infiltration and drainage, and retardation facilities such as ponds, etc.

A combination of these techniques has been employed over time in the Juba and Shabelle basins. The known non-structural measures involving early warning are set out in section 4.

In both rivers, and particularly the downstream reaches, many large and medium scale engineering and irrigation schemes were functioning in the pre-war period. On the Juba these include the Fanoole and Mogambo irrigation schemes, the Juba sugar project and the Mogambo flood relief canal. On the Shabelle these include the Jowhar Offstream Storage Reservoir, Duduble flood relief canal, Balcad barrage, and the many canals of the lower reaches. A set of key documents relating to these works is included in Annex C.

Since the war all major schemes have fallen into disrepair although the rehabilitation of canals and embankments continues to be routine work for some agencies. The El-Nino floods of 1997/8 wiped out this work and since then rehabilitation has focussed on small to medium scale interventions in embankment protection and canal clearance. The work continues to be necessary because communities often break levees during low flows, and then request assistance for strengthening them as flows rise. There are still areas where major El-Nino breaches in river embankments are evident (eg. the west bank of lower Juba).

Some of the flood control work is carried out privately, or is sponsored from private sources. The majority, however, is managed by international agencies (eg. FAO, ICRC, WFP, CEFA, CINS, Concern, CARE, ADRA, Agrosphere, etc.) and carried out by local communities, NGOs or contractors. The work is co-ordinated in Nairobi through the Agricultural Working Group (AWG) of the SACB Food Security and Rural Development Committee (FSRDC). The AWG recently sanctioned the development of an Irrigation Information System (IIS - developed by AFRICOVER with EC funding) to ensure that all relevant data is recorded, and so develop a strategic overview. The IIS is not yet operational: it is therefore not possible to offer a list of flood control projects completed, ongoing and planned.

4. Flood Warning

Evidence worldwide suggests the greatest benefit accrues from adequate technical advice and community preparedness in advance of floods linked to the establishment of a flood warning system (Xiao Lin-UNESCO IHP 1999). The importance of the advance preparation cannot be over emphasised, because the time scale of floods is too short to permit the development of an action plan, deployment of equipment, and establishment of communication channels after the flood threat becomes evident.

A generic early warning system for any large river requires:

- **Forecast procedures**
- **Rainfall and streamflow observation**
- **Rapid, reliable communication systems with emergency backup**
- **Flood warning co-ordination**
- **A warning dissemination plan**
- **Preparedness planning**

An effective Early Warning System for the Juba and Shabelle rivers requires the same.

It is normally the role of the Ministry of Agriculture to send a clear advance warning when flood events are likely, and to co-ordinate flood preparedness and response. Clearly this is not possible under the current circumstances. Ideally a counterpart "*unified command and disaster management system*" should be permanently in place, but this is also not the case. To an extent the 97/98 Flood Disaster Evaluation (Bradbury and Coulthan-DfID/USAID/SIDA 1998) stimulated policy for more effective flood planning and response, and it would be fair to say that a loose operational framework is now in place amongst the international agencies. Evolving on a case-by-case basis, if floods are predicted or are happening, baseline information is gathered first through the SACB AWG and then passed onto the SACB at large. In major crises the Humanitarian Response Group (HRG) is mandated to co-ordinate.

It is the consultants finding that the existing framework needs improvement. It is therefore proposed that FAO to catalyse an early warning system based on the generic system as outlined above. It is therefore worth examining the current state of play in comparison to the proposed system, so that recommendations can be made on where to strengthen procedures.

4.1 Forecast procedures

The aim of flood forecasting is to predict the flood peak level, the time and discharge in a specified river, at a specified place. This does not currently exist for the Juba and Shabelle.

Until such time as flood and flow forecasting measures are in place, rainfall forecasts from the basins, and particularly the Ethiopian highlands, are the best indicator of predicted flood. These can be accessed from the Drought Monitoring Centre (DMC) in Nairobi (www.meteo.go.ke/dmc), who produce a three-monthly rainfall outlook. The DMC is a technical agency mandated under IGAD, and is therefore by implication, mandated by the Transitional National Government of Somalia.

4.2 Rainfall and Streamflow observation

Rainfall is the primary hydrologic input, and stream flow the primary determinant of flood. Because 90% of streamflow originates in Ethiopia it is essential that information from there is available as input to the early warning system in Somalia. However, there are great difficulties associated with cross-border Ethiopian-Somali information exchange, and, for whatever reason, access to Ethiopian data from

Nairobi is inadequate. During this synthesis extensive efforts were made in requesting information from relevant institutions in Ethiopia, including the FAO office: There was no response.

Rainfall records go back to the early 1900s for the Ethiopian and Somali catchments, from a range of sources and projects. The most comprehensive pre-war data set from Somalia was put together under the Ministry of Agriculture/FAO Food Early Warning System project. A good data set for the Ethiopian catchments is available from the Climate Monitoring Unit of the UEA in the UK. There are also archive data covering the basins available from FAO Rome.

For real time rain-gauge recording the state of the Ethiopian network is not known. In Somalia there are one or two functional rain-gauges, but reliability is generally poor and none are linked into the Global Telemetric System (GTS). GTS records are preferred as a means of calibrating satellite derived estimates. Dekadal, remotely sensed, cold cloud duration (CCD) derived rainfall estimates at a scale that covers the river catchments are available from FEWS and the DMC in Nairobi. The critical issue in flood management though is to reduce the time lag from the first rainfall estimate, to the delivery of information needed by decision makers in flood warning. In extreme events 10 days lag may prove too slow (though not so much to *predict* the event as to *prepare* for it). However, CCD rainfall estimates currently provide the best early warning indicator of flood events.

In Ethiopia the streamflow records of the Juba, Shabelle and the tributaries are not available in Nairobi. Real-time data collection is probably ongoing on the Ethiopian Shabelle at Hamero Hedad, Gode and Kelafo and possibly Malka Wakana, Imi and Burkur. Current real time data collection on the Ethiopian Juba tributaries is not known. It is possible that the IAHS Global Run-off Centre in Koblenz, and FAO Rome both have archive data for streamflow in Ethiopia. There is also an Institute of Hydrology (UK) archive but the extent of the coverage is not fully known.

In Somalia streamflow observation probably began as early as 1925, but in earnest in 1951 at Luuq and Belet Weyne. In 1963 FAO funded a Water Resources study and established a network of staff gauge and autographic river level and flow gauging stations on each river that lasted more or less until the outbreak of war (Lockwood Survey-FAO 1966, Gemmell-FAO 1982).

The most comprehensive pre-war river data set was put together under the Ministry of Agriculture/DfID Hydrometry project, which lasted from 1983 to 1990. The project developed the HYDATA data processing and analysis system. It established rating curves for 12 stations (figure 5), developed a river flow simulation model, and a flow forecasting model to predict downstream flow up to one week in advance of flows in Luuq and Belet Weyne. A summary of gauge station (table 3) and reach characteristics (table 4) is presented below. Annex B gives hydrologic characteristics for the gauging sites. The use of this model as an early warning mechanism was curtailed by war, with most the staff-gauges and stilling wells finally wiped out by the El-Nino floods of 1997/98.

Gauge Station	Altitude (m.amsl)	Max. Width (m)	Max. Depth (m)	Max. Flow cumecs
Juba				
Luuq (LQ)	**142.6**	**140**	**9**	**1800***
Bardera (BA)	**89.5**	**100**	**8**	**1800***
Mareere (MA)	**13**	**85**		**625**
Kamsuma (KA)	**8.6**	**85**	**8**	**507**
Jamaame (JA)	**1**	**65**	**8**	**480**
Shabelle				
Belet Weyne (BW)	**176.1**	**44**	**7**	**500**
Bulo Burti (BB)	**134.4**	**48**	**6**	**400**
Mahadey Weyne (MW)	**104.6**	**46**	**5**	**166**
Afgoi (AF)	**77.4**	**40**	**5**	**97**
Audegle (AU)	**70.1**	**38**	**5**	**82**

Table 3. Gauge site characteristics for the Juba and Shabelle stations (NB.1.Altitude is taken at staff gauge zero. 2. Max for Luuq and Bardera are the peak recorded flows)

Location map

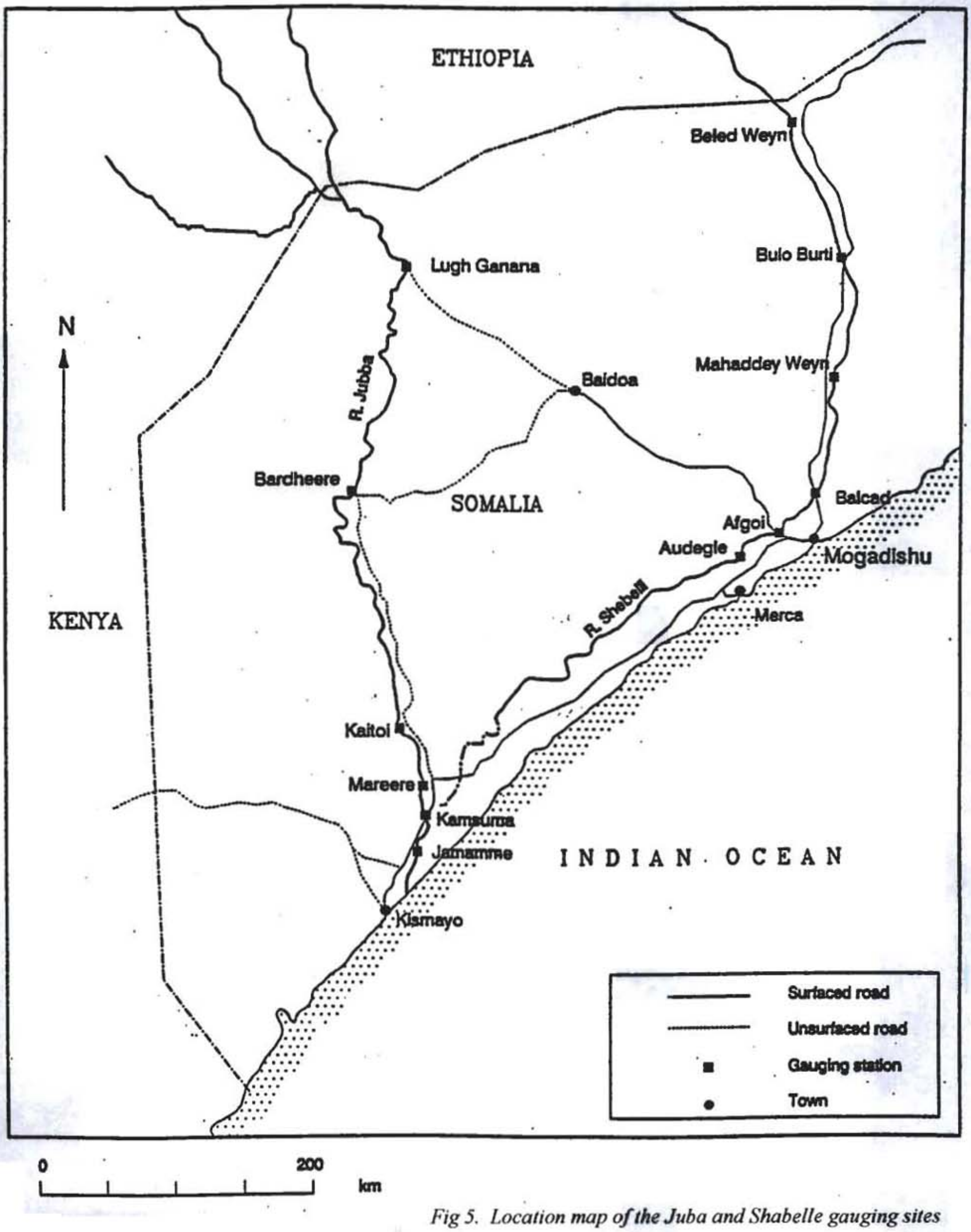


Fig 5. Location map of the Juba and Shabelle gauging sites

Reach	Length Direct	(km) Bed	Avg. Slope	Avg. Wave-speed (m/s)	Avg. Lag (days)
Juba					
LQ - BA	**165**	**234**	**2.3×10^{-4}**	**1.2**	**2.3**
BA - MA	**217**	**412**	**1.9×10^{-4}**	**1.2**	**4.1**
MA - KM	**20**	**39**	**1.1×10^{-4}**	**1.1**	**0.4**
KM - JA	**28**	**53**	**1.4×10^{-4}**	**1.0**	**0.6**
Shabelle					
BW - BB	**107**	**171**	**2.4×10^{-4}**	**1.0**	**2.0**
BB - MW	**98**	**188**	**1.6×10^{-4}**	**0.9**	**2.4**
MW - AF	**111**	**199**	**1.4×10^{-4}**	**0.8**	**2.9**
AF - AU	**35**	**66**	**1.1×10^{-4}**	**0.6**	**1.2**

Table 4. Reach characteristics between gauge sites for the Juba and Shabelle rivers

There is currently no reliable quantitative observation of streamflow in Somalia. Qualitative observation of river level is reported to the SACB Agricultural Working Group only when flood events are seasonally predicted.

4.3 Rapid, reliable communication systems with emergency backup
Flood early warning systems require a fast acting data collection process, to monitor the rise of flood waters. The transfer of data and information likewise requires a rapid, reliable communication system, preferably with emergency backup.

The cross border communication between Ethiopia and Somalia, and transmission of information from Ethiopia to Nairobi is problematic. However the communication system within Somalia, and between Somalia and Nairobi is generally very good. Agency radio networks are well established; some are mobile but most are powered from solar/generator sources with battery storage to provide 24hr back up. Private communications systems, including radio and telephone systems may also provide backup services.

When serious floods occur it is sometimes the case that communications fail because sites and equipment are inundated. In this case mobile networks carried by agency vehicles can substitute.

4.4 Flood warning co-ordination
There are two levels of co-ordination required, one is within the international agencies (SACB) and the other within Somalia.

The SACB has established a co-ordination mechanism for flood preparedness, which gives provision for early warning and response on a rolling planning basis. The mechanism is basic. However, without some *measure* of flood risk it is not clear at what level the situation passes from normal (*green*) to alert (*amber*) to danger (*red*). In this sense the flood co-ordination group needs to strengthen its co-ordination mechanism for flood *warning*. It has to be decided exactly what measure of flood risk there is, who is mandated to issue a flood warning, how it should be issued, and to whom it should be sent.

Within Somalia there is no structured flood warning co-ordination mechanism. There is a highly efficient oral network issuing news, which probably acts as a kind of advance warning, but whether this helps in co-ordination of community response to flood *per se* is not clear. The effective co-ordination of non-structural and structural measures to manage the floods along the length of the river is not viable without a functioning river authority. If anything, flood is exacerbated by mismanagement of the structural measures (sluices, gates and canals), especially in the lower reaches of the Shabelle.

4.5 A warning dissemination plan
It is a problem that there is no known warning dissemination plan within the SACB or within Somalia. A warning that is issued ad hoc, and without tangible basis, will more likely confuse than contribute to effective flood management. As with flood warning co-ordination, the *modus operandi* of disseminating a flood warning needs to be worked out.

4.6 Preparedness planning
Again there are two levels of preparedness required, one is within the SACB/international agencies and the other within Somalia. It should be noted that there is a critical link between warning and preparedness. There is little point in a forecasting and warning service providing timely and accurate flood prediction if these do not elicit the appropriate public response. As floods require the response to be more or less immediate, emphasis must be given to the organisational and sociological aspects of flood warning and control programming, and to public education.

Within the SACB the flood preparedness mechanism has recommended basic measures that are circulated seasonally. As a matter of policy agencies agree to protect lives first, followed by homes and then farmland. Responsibilities are assigned for specific reaches to agencies that agree to prepare stockpile sandbags and organise community participation to maintain embankments. A commitment to preparations for flood relief is also sought based on the pre-positioning of mosquito nets, blankets, shelter materials and food assistance.

Within Somalia flood preparedness is a seasonal activity for the riverine communities. This is based on preparation of basic flood defence structures and crop storage. Because national co-ordination of engineering measures does not exist, preparedness and flood management will remain localised for the foreseeable future. At the local level, river reaches can probably be reasonably well managed where security is stable, and where a strong sense of social cohesion exists (eg. the east bank of the Lower Juba). Within a setting of local cohesion there is no reason why local communities cannot develop preparedness plans; and through the work of the international agencies and NGOs they should be encouraged to do so.

5. Hydrologic Modelling
Based on evidence of past projects and present initiatives, three scales of hydrologic modelling for flood warning and control can be recognised. These include a regional model, where cross border information is integrated within flood monitoring; a national riverine model, based on the river flows within Somalia; and a small to medium scale model, where a high level of information is integrated for engineering flood control measures.

5.1 Regional Flood Modelling - USGS/FEWS
A number of hydrologic products are being developed by USGS EROS data center's Science and Applications Branch, the most relevant being the FEWS Flood Risk Monitoring Activity. The activity aims to provide real-time flood risk information to food security analysts and organizations in the Horn of Africa. Applications in hydrology include flood prediction modelling, flood risk mapping and interactive stream flow modelling. Product outputs to be posted on the web include maps of water status, flood risk, basin excess rainfall, and unit hydrographs.

The hydrologic model was developed initially from research in the Nzoia river of Kenya but has recently been applied to the floods in Mozambique, where the product has been further refined. The plan is to apply the model in all Sub-Saharan basins and to provide continuous simulation of streamflow, on a daily time step. USGS estimate there are some 3,000 basins, with mean area 5,400km^2.

The model is a semi-distributed physically based catchment scale hydrologic model. It consists of a GIS based module used for model input and data preparation, and the rainfall-runoff simulation. The rainfall-runoff model comprises a soil water accounting module that produces sub-surface runoff for each sub-basin, an upland headwater basins routing module, and a major river routing module. Spatially distributed inputs include the NOAA CPC estimates of rainfall, a USGS developed land-cover classification, an FAO soil layer at 1:1,000,000 scale and a 1 km resolution DEM with derivative datasets developed for hydrologic applications (HYDRO1K). An out-take from the USGS EROS data centre website (http://edcsnw3.cr.usgs.gov/ip) is attached in Annex C.

According to USGS and FEWS in Nairobi the model is likely to be up and running for the Juba and Shabelle basins well within a year's time. It is envisaged that a regional hydrologist will be in place to provide backup and field support; and may include the mandate to issue flood warnings for both rivers.

It is to be hoped that many of the uncertainties of the *level* of flood risk will be resolved at the time the hydrologist is in place.

5.2 Flow Forecast Modelling for the Somali Reaches – HYDATA/CEH
The Ministry of Agriculture/DfID Hydrometry project 1983 - 1990 was a systematic river study including measurement and forecasting. Old gauging stations were upgraded and new ones installed. Data processing procedures were reviewed and the HYDATA database system (now used widely and internationally) developed.

HYDATA was used to develop rating curves for all gauge sites, which were then converted to flows. A simple river simulation model, based on correlation of events between stations over observed time lags, was then developed as a quality check for data. This led to the production of the first Hydrometric Data Book for Somalia, including daily river flows 1951 - 1989, and hydrologic statistics for both rivers.

A flow forecasting model was then developed for use on both rivers. Correlation between stations were refined using the RIVERI program, and a flow routing algorithm developed to account for flood peaks and the inflows, outflows and over-bank storage that occur during flood events. For high flows a special case of the Muskingham Cunge routing model was used that gives a reasonable approximation to the kinematic wave equation, in this case providing an acceptable form of correlation that gives the required hydrograph response.

A combination of correlation and flow routing techniques were thus used to model river flows. Forecasts of up to one week in advance could be obtained based on radio data received from the gauging stations at Belet Weyne. For the Shabelle a simulation model for the Jowhar Offstream Storage reservoir was also included. Information on HYDATA and the Hydrometry project is available from the Centre for Ecology and Hydrology website (www.nwl.ac.uk/ih/www/products/bswhydata) and as attached in Annex C.

5.3 Hydraulic Modelling for Structural Measures in Flood Control and Irrigation
Since the 1980s computer simulation models have been widely used in the development of engineering measures for flood control, channel conveyance, irrigation and drainage. There are a wide variety of software programs now available to choose from, most are based on establishing geometric parameters before applying energy or momentum equations of flow and transport.

At the small to medium scale in Somalia these techniques may find a wide range of applications, including flood control structures, flood plain attenuation, and the design/rehabilitation of hydraulic structures (canal networks, bridges, weirs, culverts) for drainage and irrigation schemes. Modelling is likely to add value where flood control, drainage and irrigation networks are sufficiently complex that a staged approach to engineering work is required.

Modelling at this level would also be useful because a high level of detail is generally required as input to the initial geometric parameters. This may either be input to, or derived from, the GIS applications that are now being developed for Somalia (eg. AFRICOVER, IIS, DIMU, etc). The coupling of GIS with hydrologic modelling is a logical direction to go.

The three scales of model are all potentially useful in Somalia. Immediate needs are for early warning forecasting, for flood monitoring on a real time basis, and for developing preparedness by running simulations to identify risk zones. As models are developed elsewhere the range of potential applications will increase for Somalia. Regarding the three models outlined there are interesting synergies between the three approaches. A first challenge would be in matching the application scales to the different uses and users. However, the economic advantage of developing models needs relating to clear improvements in flood programming, which although evident at the regional scale, is not yet proven at the smaller scale.

6. Opportunities and Synergies for FAO
There are considerable opportunities for FAO to strengthen its involvement in flood warning and control for the two rivers. The hydrology demands it, and the humanitarian imperative is clear. FAO has a considerable worldwide experience and technical resources in water resource management and it should

be possible to use this comparative advantage to develop a program that overrides the current tendency to manage the *response* to extreme events, rather than *planning* for, and then managing them.

It is not the intention here to present the details of the proposed program. This should be done through a program formulation process where options can be explored, and the economic, social and environmental benefits can be worked out. Rather, the intention is to suggest synergies with the relevant FAO projects at work in Somalia, and to make for recommendations for further work.

6.1 FSAU

The Food Security Assessment Unit is in its third phase. One of the main results that is expected to be produced is "*an information system for purposes of early warning of potential food shortages or other factors affecting the food security situation of population groups in Somalia, and which require short term interventions, established in collaboration with FEWS and other development partners*". Among the activities in achieving the result are:

"*To establish an operational rainfall and river monitoring system based on remotely sensed rainfall and vegetative data, and regular field reports from FSAU field monitors and other partners.*" and "*In collaboration with various partners, strengthen the Somalia rainfall network by increasing the number and coverage of reporting stations.*"

It is foreseen that these activities are aimed at a better estimation of crop production rather than a contribution to flood prevention and control, given that FSAU's role is more to disseminate the early warning information received from its partners. FSAU will therefore not be forecasting the occurrence of events like floods and other disasters, but it is forecasting the impact of those events on the food security situation at district and food economy zone level. This implies running a wide range of scenarios based on seasonal and ad-hoc assessments, and comparing baseline information with real time monitoring information. Risk analysis can then be carried out on a "problem specification" related to the impact of the event (e.g. flood, drought, livestock ban, crop failure, etc).

In terms of supporting the "Flood Early Warning and Control" initiative, and apart from information dissemination, FSAU have stated that they could strengthen their baseline information and expand the risk analysis by building up risk factors associated with flood. Although baseline food economy profiles (figure 6) already refer – in a very simple way - to hydrological risk factors, improved flood management would require more detailed knowledge of the community coping mechanisms (ie. how do communities normally prepare themselves for flood? How do they normally coping with a flood event? To what extent are floods beneficial (crop production) or prejudicial (humanitarian concern) to the food economy group? etc.). Although additional resources would probably be needed for field assessments to strengthen baseline information and knowledge of local flood management, it is clear that such an approach could bridge the gaps identified in community flood preparedness planning and response.

Another area where excellent opportunities exist is in the development of the rainfall and, to an extent, streamflow gauging. Currently FSAU is fixing limits to the expansion of primary data collection by field monitors, so the daily collection of rainfall and streamflow data will remain outside their terms of reference. However, the value of quantitative rainfall data is recognised by FSAU as an additional and important indicator for crop production assessment as well as for the prediction and follow-up of the pasture condition. Moreover, data from ground based gauges is usually required to calibrate satellite derived estimates. It can also act as a useful check for qualitative information coming from the field. Therefore, in collaboration with FEWS and participating NGOs, FSAU intend to maintain a network of rain-gauges where quality standards in rainfall recording meet international norms, where data transmission is standardized and data storage centralised. FSAU will then collect and store data from NGOs and partners on a dekadal or monthly basis (which is unfortunately too long a time frame for use in flood events).

To date rainfall data collection from Somalia post war has not been convincing. FAO can therefore add substantial value to this process through technical support to FSAU and FEWS. Technical support might focus on the setting and monitoring of an internationally recognised standard for rainfall and agro-meteorological data collection in the more stable areas of Somalia, and the production of translated technical manuals. FAO can also focus on priority developments of the rainfall network, and the co-ordination of it (as was the case pre-war). Some notes on the development of rainfall data collection in support of strengthening the early warning system are included in Annex B.

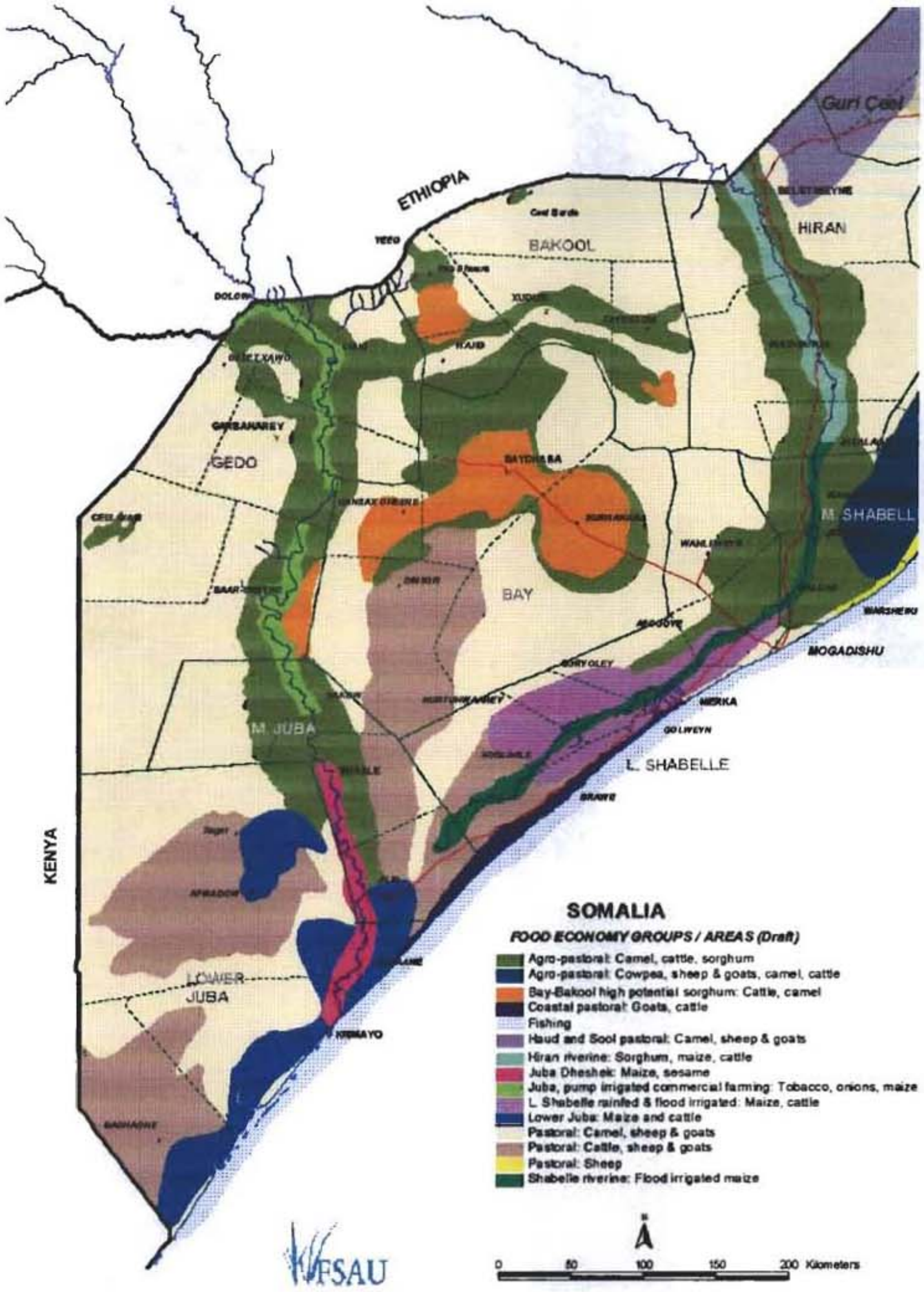


Fig 6. Food Economy Groups of the Juba and Shabelle areas

6.2 AFRICOVER

There is a considerable amount of technical expertise and resources available in the AFRICOVER Nairobi office. This includes an extensive GIS and data management facility, access to technical resources in mapping and remote sensing, and considerable human resource expertise in various environmental science and information management fields. The environmental orientation of the project is clearly focused on the potential of the natural resources, and land in particular. It is based on a solid geographic context (including topology) that can be used as reference for further geographically related information.

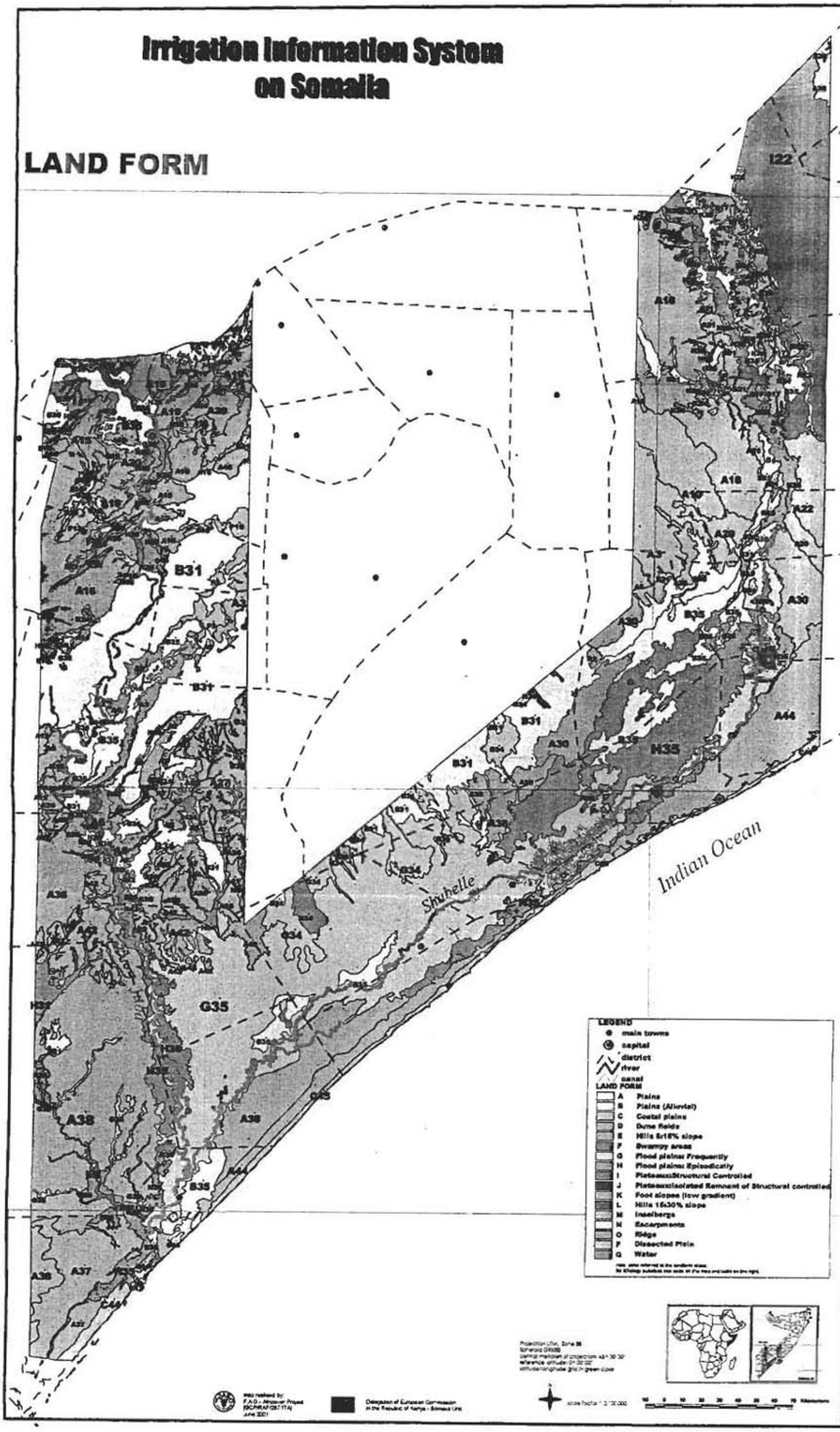


Fig 7. Land Form Map of the Irrigation Information System

AFRICOVER project integrates a range of remotely sensed data and studies into producing detailed land information for 10 countries in East Africa. The database describes in detail the environmental resources (where environmental resources cover all the recognisable features: natural resources, agricultural and pastoral areas, bare soil, man's intervention, urban area, etc.) at 1:200,000 for large countries and 1:100,000 for small countries. Ethiopia is not included in the project, and Somalia is unique in that there is no government counterpart for AFRICOVER to work with.

Thus far in Somalia AFRICOVER have worked to produce a Land System (focused on Land Cover and Land Form). At the request of the Food Security and Rural Development Committee of the SACB, an Irrigation Information System (IIS) for the Juba and Shabelle river basins based on the Land System, including a Digital Elevation Model, has been developed (figure 7 shows the Land Form map produced). The IIS is based on a synthesis of existing information. Its objective function is to be a tool that supports the decision process in selecting priority interventions for the irrigation sector. Moreover software has been produced to integrate the information flowing from the field on the status and physical measures of the existing canals.

The environmental focus is in contrast to the livelihoods based approach of FSAU, which focuses on the capacity of people in coping and reacting to crisis situations. However, there is good potential to correlate both approaches through adaptive research that is based on the same agro-producing land unit. This might ensure that more focused and better calibrated information is available for all the processes of crisis forecasting: eg. management, scenarios development, local population coping capacity, prioritisation of interventions and food distribution, etc.

There is thus considerable scope for synergistic programming with AFRICOVER in Somalia. The members of SACB Agricultural Working Group have clearly stated that information on water and land is a priority on Somalia, and the work of AFRICOVER could be the starting point for developing a wider framework for a Water and Land Information System. Such information would be oriented to a wider context, rather than being solely flood related, and could be of great value in the development of a thematic approach to water and land management. Moreover the office resources available and the tools specifically developed, could be made available to develop specific applications and analysis.

7. Recommendations

The el-Nino floods of 97/98 demonstrated the impact of serious flooding in Somalia. The community of Somalia and the international agencies working there were unprepared for the flood, and the subsequent evaluation highlighted the need for effective early warning and seasonal advance planning. Unfortunately, as the memory of the 97/98 floods recedes there is likely to be a tendency to resort to ad-hoc flood management; and it is entirely possible that by the time the next serious flood occurs (*as it certainly will*) the Somali community and the international agencies will again be caught unawares. The problem is exacerbated by the lack of long-term hydro-technical expertise for Somalia, and limited resource allocation for flood management in the Juba and Shabelle basins.

Effective flood management must be based on advance preparation first and foremost. Flood risks can be predicted with a fair degree of confidence but the calculation of the risk takes time and money. Many of the adverse effects of flood can be mitigated through adequate warning, control works and management, but there must be an understanding of the problems and knowledge of effective solutions. To be adequately prepared it is necessary to keep flood open and on the agenda of the Somali community and international agencies. This requires continuity of programming, but the cost of being adequately prepared is likely to be recouped against the human, environmental and economic impacts of an extreme flood event.

FAO has the potential to play a key role in flood warning and control for the Juba and Shabelle rivers, in both the short and longer term. Through mobilising resources, providing expert technical assistance, and stimulating action at the international and local community level, it is possible for FAO to contribute to the improvements required in flood management; and in a way that demonstrates a concern and lasting commitment to the communities most vulnerable to flood events. To this end the following three recommendations; for early warning, for control, and for future programming are offered.

1. **It is recommended that FAO set out a minimum "best practise" operational standard in flood warning and preparedness, and lobby for its adoption by the SACB as soon as practical.**

Flood warning and preparedness need to be aligned to best practise in disaster management. To achieve this it is recommended that FAO produce a brief set of guidelines in flood warning for the Juba and Shabelle rivers. These can be distilled from this working paper mainly. Flood education and dissemination of information through a half day working session is further recommended. The aim will be to disseminate technical data and its analysis so that a common set of data is in use, and upgrading the current flood co-ordination and management framework, to ensure compliance of a minimum "best practise" operational standard by the SACB.

Best practice demands an early warning system that fully integrates:

- **Forecast procedures**
- **Rainfall and streamflow observation**
- **Rapid communication systems with emergency backup**
- **Flood warning co-ordination**
- **A warning dissemination plan**
- **Preparedness planning**

A management set up to handle this system for a typical flood event is shown in figure 8b (where a typical flood scenario is shown in figure 8a). A set of ***conditions*** (or general recommendations) in achieving this, and ***recommendations to FAO*** specifically, are set out below.

Critical components of best practise flood warning are:

i. The establishment of a Flood Management Group that brings together the required expertise under a permanent flood co-ordinator for both rivers.

ii. Ensuring the penetration and flow of key data, and in good time.

iii. Simplification of communications processes; minimising transmission time and routing through a clear chain of command.

iv. The establishment of a graded system for flood warning, to be issued only by the flood co-ordinator.

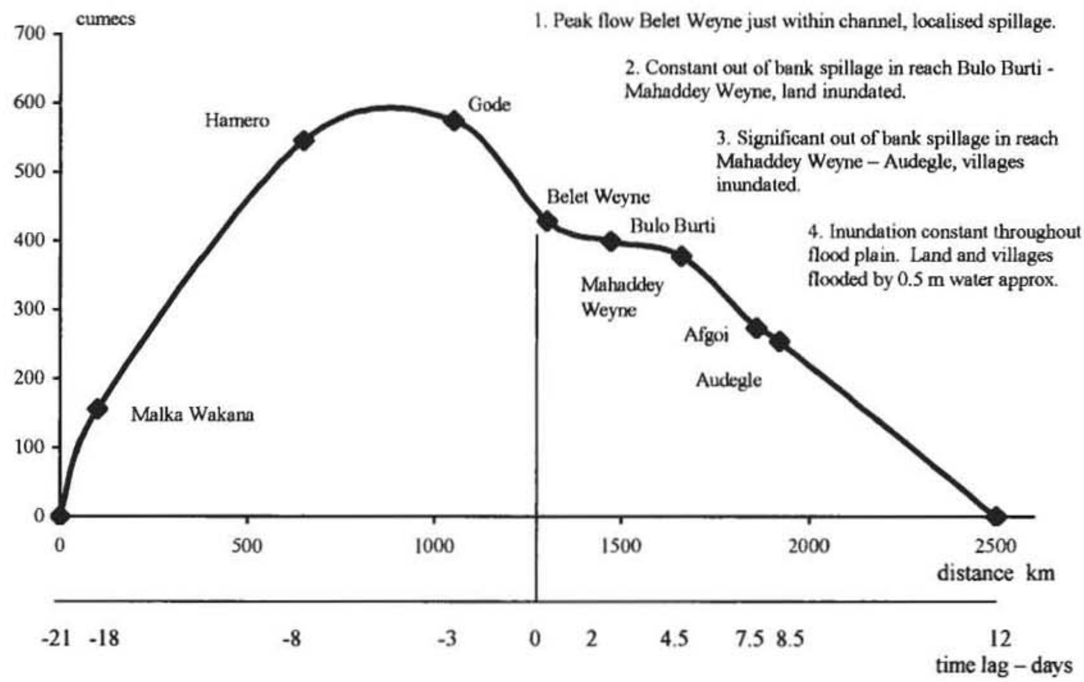
v. Linking the warning to effective community flood planning and response.

The management set up recommended in fig 8b brings together all the expertise required to manage the flood cycle, from forecasting to relief operations. It is assumed the group will only be as busy as the river determines; but it should sit with a permanent constitution and fulfil a continuous monitoring role. The group should relocate from Nairobi to Somalia as soon as possible, at which point the counterpart flood co-ordinator in Somalia would probably be from the Ministry of Agriculture. The set up serves to strengthen interagency organisation, but its effectiveness is conditional on commitment from all actors.

Condition – A clear warning message based on a severity index is required, eg.

All Clear (Green) - when seasonal forecasts indicate normal or below normal catchment rainfall.
- during Dec thro March when rainfall and river conditions are normal.
- during March thro Dec when rainfall and river conditions are below normal.

Fig 8a. Approximate discharge hydrograph for a uniform wave 1 in 20 year flood event along the length of the Shabelle river



Chronology of a 1 in 20 flood on the Shabelle river (t in days)

t – 60 Primary input: RAINFALL FORECAST
Bulletin produced by Drought Monitoring Centre. 1st indicator – above average anomaly predicted
FLOOD WATCH level warning issued
Flood preparedness programming tightened

t – 18 to t – 3 Primary input: ETHIOPIAN RAINFALL and STREAMFLOW
Information disseminated from FEWS regional hydrologist. 1st Flood Risk Map produced. 2nd Early warning indicator – flood severity predicted with reasonable level of accuracy.
FLOOD ALERT warning level issued
Mobilisation of relief measures begins

t = 0 Primary input: BELET WEYNE STREAMFLOW
Information disseminated from stage reading of 6.5m. Discharge at 430 cumecs. Flow forecasting model and FEWS flood risk map correlated for "at risk" analysis
SEVERE FLOOD ALERT warning level issued
In country flood co-ordinators mobilise preparedness plans. Mobilisation of relief measures continues.

t + 2 to t + 4.5 Primary input: REACH STREAMFLOW
Daily monitoring through remote and aerial surveys. FEWS and UN Flood bulletins produced.
SEVERE FLOOD ALERT warning level maintained
In country co-ordinators identify areas worst hit. Relief supplies delivered. Reporting and broadcasts through radio (eg. BBC Somali service).

t + 4.5 to t + 12 Primary input: FLOOD INUNDATION
Daily monitoring through remote and aerial surveys. FEWS and UN Flood bulletins produced. Flow and risk models calibrated from remote and aerial surveys to enhance future forecasting.
SEVERE FLOOD ALERT warning level maintained
In country co-ordinators identify areas worst hit. Relief supplies delivered and relief effort mobilised. Relief efforts upstream underway and coming on line downstream. Reporting and broadcasts through radio (eg. BBC Somali service).

t + 12 plus Primary input: FLOOD INUNDATION
Daily monitoring. Lower Shabelle under at least 0.5m of water. Full scale relief efforts where required. When flood abates return to ALL CLEAR warning level.

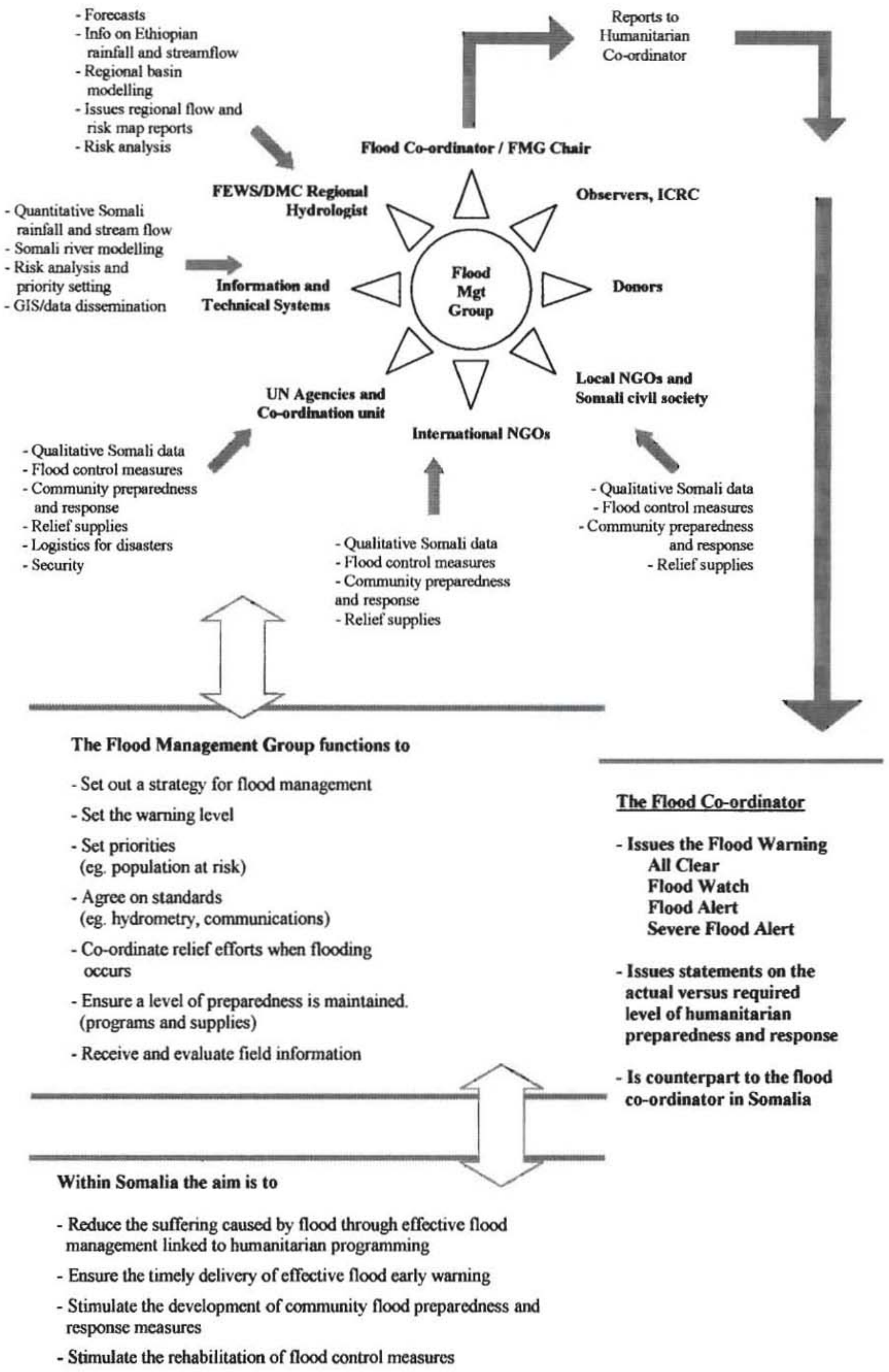


Fig 8b. Outline of the recommended Flood Management Group

Flood Watch (Amber)- when seasonal forecasts indicate above normal rainfall is due.
- during Dec thro March when rainfall and river conditions are above normal but no out of reach spillage has taken place.
- during March thro Dec when rainfall and river conditions are normal or above normal but no out of reach spillage has taken place.

Flood Alert (Red)
- when Ethiopian catchment rainfall is above normal and flood is predicted by a recognised forecasting model.
- when a flood wave in Luuq exceeds 820 cumecs.
- when a flood wave in Belet Weyne exceeds 250 cumecs.
- when river conditions are well above normal and out of reach spillage occurs anywhere along the rivers that endangers human life.

Severe Flood Alert
- when severe out of bank spillage occurs anywhere along the rivers that endangers life, property and crops.

The conditions to meet in strengthening system elements are then:

a. **Flood forecasting**
Condition - Rainfall forecasts should be regularly sought out by the flood co-ordinator from DMC.

Condition - When the FEWS flood risk monitoring project is operational, a regular update must be sought from the regional hydrologist by the flood co-ordinator. The regional hydrologist should be an active member of the flood group.

Condition - Flood forecasting is to be based on a model that can predict the flood peak level, the time and discharge in the specified river, at any specified location.

b. **Rainfall and Streamflow observation**
Condition - Real-time rain-gauge data should be acquired from Ethiopia (difficult!) and transmitted to the DMC and FEWS. This can be used for calibration of remotely sensed estimates and as an early warning indicator when fed on to the flood co-ordinator.

Recommendation to FAO - A rain-field gauging station (see Annex B) should be developed in the region to calibrate remotely sensed estimates. Where ever possible rehabilitation of single gauge sites should focus on gauges previously linked into GTS, and these should be re-linked to GTS as soon as practical. Gauges should be rehabilitated and operated to a standard accepted by the WMO. FAO can support this by producing a monogram of rules for rainfall observers, and through regular field inspection of the gauge network. A communication system is required to ensure that rainfall data is regularly transmitted to DMC and FEWS. The regularity depends on the event and may include short time frames (down to one day) where extreme events occur.

Condition - Real-time stream flow data should also be acquired from Ethiopia and transmitted to the DMC and FEWS. This can be used to calibrate the FEWS flood model being developed for the rivers, and can act as a direct early warning indicator when fed on to the flood co-ordinator.

Condition - Qualitative streamflow data is useful and should be reported regularly to the flood co-ordinator and FEWS. It is suggested that data be co-ordinated within Somalia and that a co-ordination framework for transmission of data be established by the agencies operating along the river.

Recommendation to FAO - Quantitative streamflow data is much more useful. Rehabilitation of gauging sites is required with Belet Weyne and Luuq the first priorities. Bulo Burti and Bardera are second priorities for a flow simulation model is to be developed. Downstream gauging at Jamaame and Audegle are in indicator of the severity of inundation (but will not be so useful for early warning) and should be prioritised over other downstream stations.

A brief study of the old gauge sites is required to develop technical specifications and costing. Rehabilitation of the river gauging sites should be to an internationally accepted standard. It should therefore be supervised by an engineering hydrologist or engineering company. The technical specifications of the pre-war hydrometry project should be replicated wherever possible, to ensure the continuity of data series and hence the power of flood forecasting. Priority actions are to ensure the gauge zero datum level is identical to the pre-war level (see table 4), verifying the bed and flow control, establishing an up to date stage-discharge relation and correlating this with the pre-war coefficients. Rehabilitation plans might also include a stilling well, with a telemetric stage recorder that can be interrogated remotely, and thus linked into a remote river monitoring system.

It is further recommended that for stream gauge rehabilitation to be effective an integrated approach will be required that includes the installation of a radio communication system, localised flood co-ordination and the development of a community flood management plan.

Condition - For receivers of primary rain-gauge and/or streamflow data (eg. FEWS, DMC), such information should be analysed and reported to the flood co-ordinator at the same time scale as it is received. There should be a maximum of one delay during the flood watch and flood alert stages.

Recommendation to FAO - It is recommended that CEH be contacted to see to what extent the HYDATA modelling system can be usefully redeveloped for the current operational climate in Somalia. It is also recommended that FAO co-ordinate with USGS/FEWS and CEH HYDATA to assure the complementarity and potential of both modelling approaches for flood early warning. The extent to which FAO resources (eg. AFRICOVER, FSAU) can add value to modelling the rivers should also be explored.

c. **Rapid, reliable communications with emergency backup**

Condition - Communication networks need to be as simple and direct as possible, and this should be reflected in the flood management structure.

Condition - The level and coverage of communication systems in Somalia appears to be adequate for the task. It is advisable for an inventory of mobile communications systems to be kept and updated each year before the Gu flood.

Condition - Radio frequencies and communications protocols (including any codes) are a matter of common interest and need to be agreed within the flood management group.

Condition - Somali to Somali broadcasting of river conditions from the Ethiopian Ogaden into Somalia can provide a useful direct early warning. It is recommended that agencies in Somalia try to find out to what extent this already goes on, and how it can be legitimately promoted. Regional co-ordination will be required to strengthen communications links and information exchange between Ethiopia, Kenya and Somalia. The UN system is ideally placed to help strengthen regional links but is not yet doing so.

d. **Flood warning co-ordination**

Recommendation to FAO - It is recommended that a permanent flood co-ordinator is appointed/elected and that FAO provide in kind support for his/her functioning (eg. admin, travel and logistics, desk space, publishing, etc.). This may be a shared resource with other agencies. It should be recognised that time, commitment and resources are required to run effectively.

Condition - Flood co-ordination along the length of the rivers in Somalia will not be achieved without a centrally respected river authority. Even if this in future exists there will still be a need for a local co-ordinator to handle local dissemination and ensure, as far as possible, the appropriate public response to the flood warning. It is recommended that agency programs along the rivers stimulate the development of flood preparedness plans, which include the appointment and training of a local flood co-ordinator.

e. **Warning dissemination plan**

Condition - The need for a level of warning has been identified. It is strongly recommended that the level of warning in place is <u>only</u> issued by the flood co-ordinator, on approval of the flood management group. The warning should be issued through the resident humanitarian co-ordinator for Somalia, and simultaneously to all agencies working in the riverine areas. The flood warning should be issued to Somali authorities through fast track channels of the SACB, and to the Somali people via media.

Condition - The warning dissemination plan needs to agreed and adhered to by all core members of the flood management group, (some of whom will need educating in flood management). It is recommended that the warning dissemination levels be developed and tested on a real-time basis over the next two years, and an evaluation of its impact on the various stakeholders made. Emphasis must be given to linking warning dissemination to community preparedness in Somalia.

Condition - The effectiveness of warning dissemination through the media needs to emphasised. In particular the radio services, such as BBC Somali service, could play a vital role. It is recommended that Bush House and the BBC in Mogadishu are contacted to see what the possibilities and constraints are.

f. **Preparedness planning**

Recommendation to FAO - Within Somalia it is critical to stimulate community preparedness. Even if a respected central government and river authority returns it is still local community response that has the greatest impact on flood mitigation. Local communities must therefore have a say in how they prepare, and should receive technical support from FAO equal to their level of commitment. However, the extent to which Somali communities can be effectively involved in developing and implementing community flood-action plans needs further study. It is therefore recommended that FAO and FSAU undertake a joint study to assess the capacity, and needs, of riverine communities in this respect. The aim for FSAU would be to strengthen its baseline information and knowledge of local flood management.

Recommendation to FAO - Effective preparation for flood requires community participation that, at its simplest level, requires little or no financial resources. Achieving a good level of participation requires public education. Based on the outcome of the proposed study into preparedness planning, it is recommended that FAO provide technical support to the development of an appropriate form of public education.

Recommendation to FAO - It is strongly recommended that agencies and INGOs include support to community flood preparedness plans within their riverine rehabilitation programmes as a matter of course. Flood event should not be separated from "normal year programming"; an integrated approach to local river and land management is foreseen. It is recommended that where FAO are directly supporting INGOs or NGOs, resources are always allocated for community preparedness planning. Participative approaches (through PRA, COPP, etc.) are likely to result in the most productive outcomes.

Condition - It is strongly recommended that agencies and INGOs include an element of flood preparedness within their own programs. This should include at least a stockpile of relief supplies (mosquito nets, blankets, etc) and a back up communication equipment where inundation is possible.

Condition - Within the proposed flood management group it is recommended that the flood co-ordinator be empowered to issue reports on the global level of preparedness required and achieved. This requires knowledge of the overall flood risk matched against the available technical resources and relief supplies. This information should be readily available within the flood management group. As a matter of course an inventory of agency resources and/or commitments should be sought and recorded whenever the warning reaches flood watch stage. To translate the preparedness into effective delivery of relief the inventory should be updated continuously throughout the flood event, and assets matched continuously with the flood risk zones.

Recommendation to FAO - Preparedness planning can be greatly assisted by modelling. It is possible to develop flood scenarios through computer simulation, and to use the simulation to identify zones of low, medium or high risk of inundation. The FEWS/USGS model is designed to do this at the basin scale. It is not yet clear to what extent it will be useful in small to medium scale applications however. As previously stated, it is recommended that FAO contact CEH to see if partial rehabilitation of the flow simulation model is possible (and which may be complementary to, and possibly help calibrate, the FEWS/USGS model).

The extent to which small scale modelling can add value to the rehabilitation process needs working out. It is possible that a river flow simulation model can be linked into some form of smaller scale hydraulic model that simulates flood in relation to control infrastructure. This would be useful if it helps identify priority infrastructure for rehabilitation. However, the level of information needed as input to modelling at the local level, particularly in the irrigated areas, requires expert knowledge and a high level of land and infrastructure detail, which would be costly and difficult to obtain. FAO could conduct the necessary surveys, but in the first instance, it is recommended for FAO to stimulate use of the Irrigation Information System more extensively, and to see what level of information exists, or can be acquired. Opportunities for small scale modelling, as an aid for preparedness planning, but also for irrigation and drainage, might then be developed on a pilot basis.

At all scales of modelling, accurate baseline information of the land and water domain is required as input. Remote sensing and ground data are complimentary inputs and FAO could add substantial value to modelling approaches through contributing its expertise in water and land informatics. In the first instance the potential for the AFRICOVER project needs to be elaborated.

Condition and Recommendation to FAO - It is must finally be stressed that preparedness planning will be best served by an integrated approach, ie. one that values the diverse approaches of the various stakeholders. To achieve this requires strong co-ordination and it is strongly recommended that FAO take a leading role.

2. It is recommended that FAO continue to develop its program in flood control, taking account of the following;

- Flood is a complex event on both rivers and there is a need to develop an overview of how events in localised reaches fit within the national context. Considering the FAO mandate for flood, irrigation and drainage, it is recommended that FAO lead the development of a strategic overview. This requires a holistic approach, and an in depth study of 2 to 3 months work that considers engineering, economic and social aspects. A private consultancy by tender to a suitable national firm with an proven track record in civil engineering should be considered. The aim of the study will be to;

i. Collate and disseminate an inventory of flood control projects completed, ongoing or planned since the El-Nino floods of 1997/98 (since the El-Nino event wiped out much of the previous work pre 97/98 work is probably not relevant). FAO to assess project methodologies and successes where possible, in order to develop "best practise" programming in flood control, irrigation and drainage.

ii. Collect and assess the available historic studies in flood control, irrigation and drainage. Determine the importance of the various projects for flood control through technical and engineering analysis.

iii. Collate and disseminate an inventory of flood control infrastructure that is currently non-functional, and which, by being non-functional, increases the risk of major flood events and/or the vulnerability of local communities to it.

iv. Determine flood risk zones in the riverine areas. Determine priorities for strategic rehabilitation of infrastructure based on its importance for flood control and the ability of local communities to operate and maintain it.

v. Use the Irrigation Information System and the Water Information System to assemble the information in a standardised format. Use GIS and a standard reporting format to disseminate the information in a way that is easy to interpret and understand.

- Within FAO projects at the local level (eg. the ongoing project along the lower east Juba) there is a successful approach and positive results. However, it is always useful to back up the practical work with the collection and storage of data on the status of flood, irrigation and drainage infrastructure. It is therefore recommended that FAO use more extensive use of the Irrigation Information System and/or other computer based archiving. This will help build up the poor state of the information base in

Somalia, and contribute to the build up of institutional memory. A small training element for data collection and training is required when budgeting.

- The use of established engineering seems to be generally overlooked in flood control work. It is recommended that FAO consider the private sector consulting engineering companies, which usually contain depth in technical and human resources and are professionally accredited, to add value to the rehabilitation process.

3. **It is recommended that FAO develop a project in water and land management information systems for Somalia**

There is a widely recognised need to bridge the gap between the poor information environment of Somalia, and the need for good quality information to underpin decision making, humanitarian programming and strategic development.

The problem of how to merge different scale of information with the various users and approaches to information management for Somalia needs a progressive solution. It is therefore recommended that FAO begin to formulate a program in water and land management information systems for Somalia. This will include line management of the Water Information System and Irrigation Information System for Somalia. Conceptually, and in order to offer the best option for long term sustainability, the program should be a "knowledge based" one, that integrates scientific and traditional knowledge through indigenous and international partnership.

It is recommended that a sub-project line be focussed on the development of improved flood knowledge, which includes FAO contributing to the sustained management of flood warning and flood control for the Juba and Shabelle rivers. Practically, this could include technical assistance for the operation and maintenance of streamflow sites, redeveloping the HYDATA simulation model, the development of a rain-field gauging site (for use also in land science studies), and the development of community flood management plans. It will also result in a stronger, more detailed synthesis of flood warning and control for the Juba and Shabelle rivers.

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Annex A

Persons Consulted

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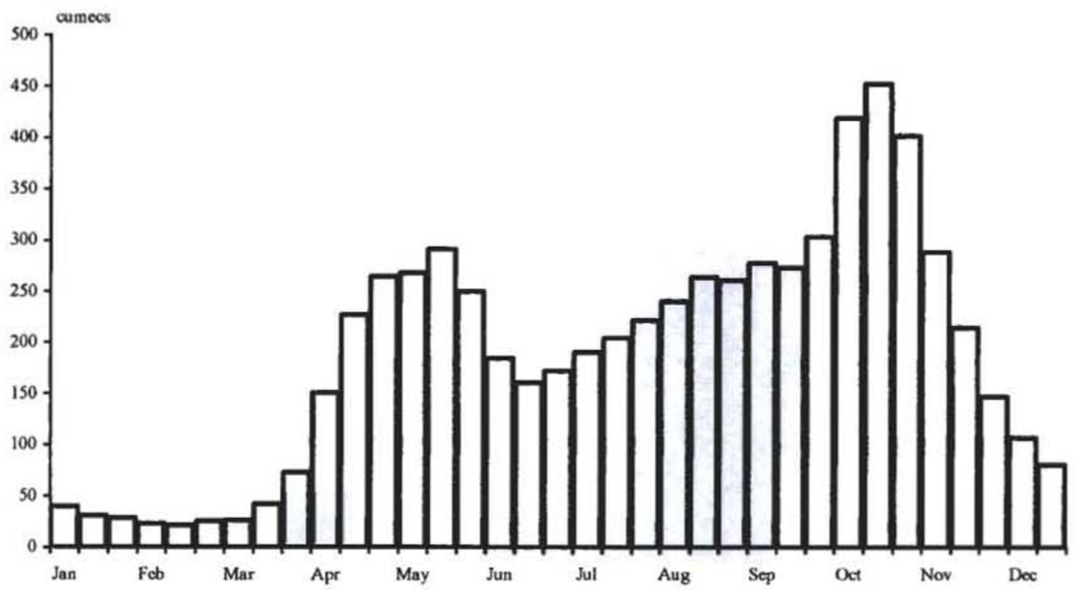
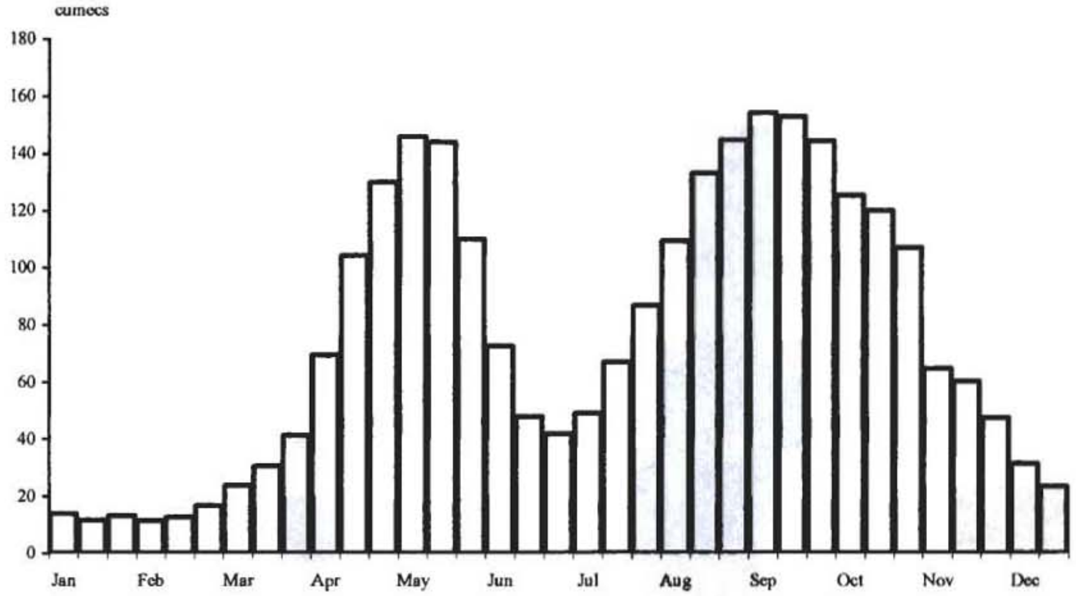
Annex B

Additional Data

A. TEN DAY AVERAGE FLOWS FOR LUUQ AND BELET WEYNE



10 day normal (median) flows at Luuq - Juba



10 day normal (median) flows at Belet Weyne - Shabelle

Normal flow is bi-modal for both rivers. Both rivers have extended low flows at the start of the year, but the patterns differ in the mid-year between flood seasons. On the Shabelle there is a sharp drop after the Gu flood, but on the Juba the drop is fairly small as the average flow is usually maintained by a succession of small flood peaks. The normal peak Deyr flood on the Juba usually occurs in early October, a month or so later than for the Shabelle.

NB. Average conditions can be represented by either mean or median flow. Of these median is more suitable because, especially during low flows, the mean can be raised significantly by the presence of one or two extreme values. The data set including exceedance flows is attached.

TEN DAY FLOWS FOR UPSTREAM AND DOWNSTREAM STATIONS: JUBA AND SHABELLE RIVERS

		Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec		
Juba		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Luuq	mean	55.5	39.4	30.5	28	22.8	21.1	25.1	25.8	42.1	72.8	151	228	265	268	291	250	184	161	172	191	204	222	240	264	261	278	273	304	420	453	403	289	215	148	107	81
80% exceedance	median	23	16.5	12.3	9.4	6.3	5.6	5.4	6	5.8	5.7	46.5	68.7	98.6	140	131	117	96.4	97.9	106	136	138	163	156	186	159	173	164	209	226	225	220	168	95	73.1	50.9	34.6
50% exceedance	**median**	**34.7**	**28.9**	**21.9**	**20.7**	**15.7**	**12.3**	**10.4**	**10.9**	**11.2**	**25.2**	**120**	**148**	**196**	**240**	**237**	**200**	**168**	**153**	**182**	**173**	**207**	**206**	**226**	**265**	**283**	**273**	**276**	**290**	**415**	**396**	**340**	**228**	**163**	**107**	**72.7**	**51.1**
20% exceedance	median	78.6	61.3	53.8	41.4	34.5	33.4	34.2	38.2	57.1	135	194	366	395	405	404	353	260	217	217	254	255	257	327	348	349	387	397	384	601	715	464	390	338	224	144	127
Jamaame	mean	70.5	48.3	34.5	27.3	23.3	18.7	17	20.4	27	48.6	92.9	149	200	238	259	239	210	166	154	169	178	192	211	229	242	246	253	253	311	353	353	323	257	193	139	101
80% exceedance	median	31.1	23.9	15.1	10.7	7.3	4.3	2.9	1.2	1.7	4	4.6	35.4	62.7	91.8	142	118	92.6	85.2	86.7	99.7	115	136	152	163	161	161	151	161	213	202	209	195	138	82.6	58.4	40.6
50% exceedance	**median**	**45.3**	**33.2**	**29.1**	**26.1**	**20.5**	**15.5**	**12.6**	**8.7**	**9.8**	**14.7**	**35.5**	**134**	**158**	**242**	**252**	**195**	**180**	**158**	**141**	**156**	**179**	**182**	**205**	**208**	**246**	**235**	**267**	**245**	**326**	**407**	**391**	**314**	**214**	**146**	**96.1**	**66.4**
20% exceedance	median	100	72.6	54.8	40.5	37	25	36.3	28.9	35.9	47	168	234	394	412	409	387	309	249	218	260	235	245	262	303	319	348	346	354	405	476	472	448	384	312	224	129

		Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec		
Shabelle		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Belet Weyne	mean	17.8	13.8	11.5	13	11.2	12.5	16.5	23.8	30.5	41.4	69.5	104	130	146	144	110	72.5	47.7	41.9	49.1	67	86.9	109	133	145	155	153	144	126	120	107	64.7	60.2	47.5	31.4	23.3
80% exceedance	median	6.2	4.3	3.2	3.1	2.9	2.9	2.7	2.9	2.7	4.5	19.3	33.9	51	61.3	77.4	38.8	22.6	19	16.9	23	42.6	65.7	87.3	104	90.8	103	95.4	87.6	74.2	61.6	42.5	21.8	16.4	11.9	9.9	7.8
50% exceedance	**median**	**11.2**	**9.7**	**9.2**	**8**	**8.4**	**7.8**	**10.4**	**10.4**	**10.8**	**18.4**	**56.3**	**96.9**	**90.4**	**122**	**123**	**74.1**	**45**	**33.8**	**40.3**	**50.6**	**62**	**86.4**	**119**	**138**	**149**	**163**	**146**	**121**	**114**	**105**	**86.2**	**44.2**	**31**	**23.5**	**17.2**	**12.7**
20% exceedance	median	27.6	23.9	20.5	17.7	17.4	18.8	22.3	35.8	66	73	97	143	213	257	207	184	101	64.2	64.2	78	99.6	109	132	174	191	202	202	195	170	186	190	87.4	90.5	62.6	39.2	35.2
Audegle	mean	17.7	14.2	11.3	9.7	10.4	9.2	10.4	14.9	17.7	19.9	27.7	47.9	61.3	66.7	68.4	67.1	57.1	44.3	38.2	37.7	46	58.7	70.2	72.5	75	74.2	75.3	73.6	72.7	69.6	66.7	58.9	46	39.2	31.6	24.9
80% exceedance	median	4.7	3.5	1.1	0	0	0	0	0	0	0	1.1	26.7	33.6	43.3	50.9	45	29	15.3	15.8	17.2	24.8	41.3	61.1	75.5	72.8	73.4	70.1	68.1	65.7	52.8	44.2	29.5	19.4	14.3	10.1	6.2
50% exceedance	**median**	**11.6**	**9.4**	**8.1**	**6.1**	**5.2**	**6.5**	**5.2**	**2.5**	**2.6**	**7.5**	**19.1**	**50.4**	**69.2**	**80.8**	**83.2**	**76.5**	**63.6**	**40.5**	**35.9**	**35.2**	**44.4**	**62.6**	**81.6**	**92**	**91.9**	**91**	**90.6**	**87.4**	**79.7**	**78.7**	**79.1**	**63.5**	**41.2**	**31.6**	**22.8**	**17.5**
20% exceedance	median	34.2	29.4	21.6	17.2	15	13.2	18.8	26.9	35.1	48.3	73.2	82.4	90.7	93.8	96.5	92.6	86.5	68.9	60.7	52.1	70.9	81.5	93.6	96.5	97.5	97.5	97.1	95.3	93.3	94.5	92.8	92.9	77.1	72.6	58.1	44.1

NOTES:

B. A NOTE ON DATA

Is should be noted that Somalia is generally recognised as a data poor environment, and that there are often considerable discrepancies within and between studies. This is a constraint where long term, accurate information is required for scientific or statistical analysis.

The primary source of river data used here is the Hydrometric Data book of Somalia produced by the Ministry of Agriculture and the Institute of Hydrology (UK) in 1991. The project examined all existing data, including data sets generated by internationally funded projects, and validated a final data set, which was published in the data book.

According to the project documentation primary data availability is generally much better for the Shabelle than the Juba. The pattern differs between the two rivers, reflecting a slightly different set of projects working on hydrometry. The best quality record is probably Belet Weyne, where about 90% of all original data remains. The annual flow printouts in the Hydrometric Data Book contain comments on the data, some of which refer to the quality of the data for that year.

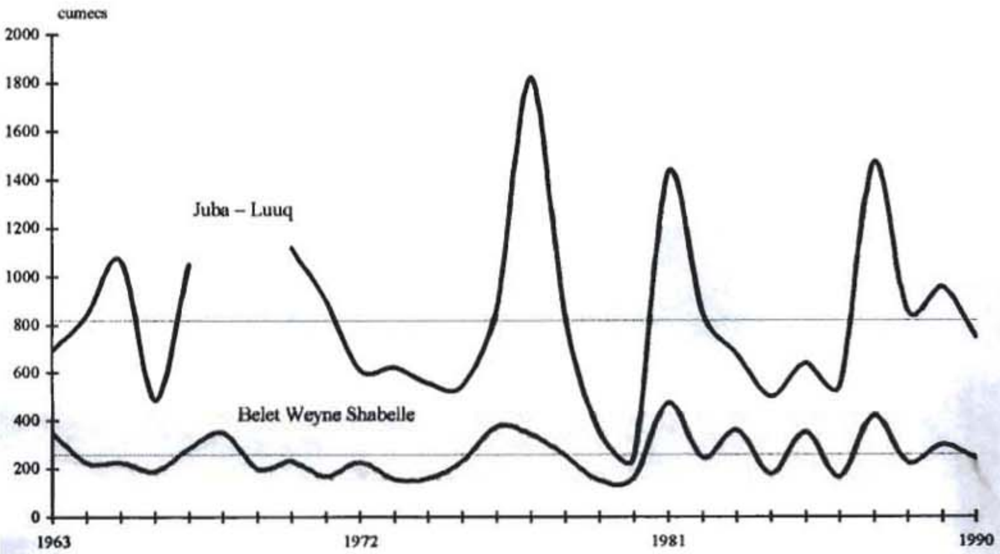
Resulting from this synthesis, there are two areas that warrant further attention from FAO.

1. FAO AQUASTAT state the global renewable water resources of Somalia as 13.5km3/pa, of which 7.5km3/pa is incoming flow originating outside the country. Analysis of the available data shows an average incoming flow for the Juba and Shabelle rivers as 8.24km3/pa. This increases the dependency ratio from 55% to 58%.

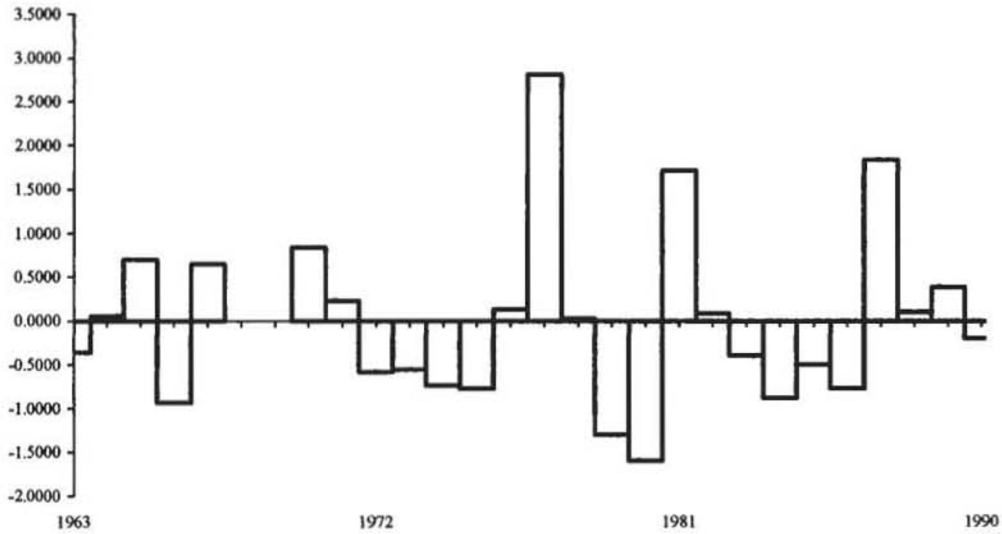
2. The Juba basin area is widely reported as being approximately 223,000 km2. According to a 1998 study by the World Resources Institute the basin area is 497,655 km2, the difference being in the significance of the contribution of the Kenyan catchment from Ewaso Ngiro East. To an extent the evidence of contribution from Eastern Kenya may be justified, as remotely sensed evidence from the El Nino floods of 1997/98 show a significant contribution to flood that extends west of Afmadu.

C. THE INTER-ANNUAL VARIABILITY OF FLOOD FLOWS

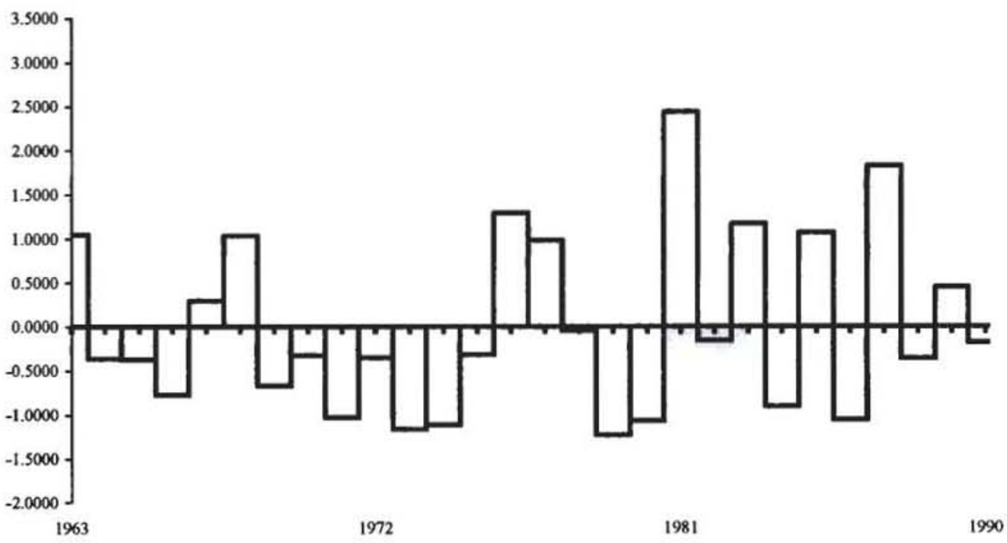
The coefficients of inter-annual variability for the upstream stations have been calculated from the 1963 – 1989 data set of the Hydrometric data book for Somalia. There is not enough Luuq data for the years 1967 1969 to be confident of an estimate. The time series of flood flows are shown below. The annual mean maximum flood flow for Luuq is 817 cumecs and the coefficient of inter-annual variation in flood flow is 46%. The annual mean maximum flood flow for Belet Weyne is 256 cumecs and the coefficient of inter-annual variation in flood flow is 35%.



A better way of describing the inter-annual variability, and showing the correlation between flood events on the rivers, is through the mean normalised anomaly of flood flow for the same time series (ie. the series have been normalised to remove any sign of trend, and then the mean deviations divided through by the standard deviation). It can be seen that the correlation of annual mean maximum flood events is generally strong through the series. However, 1977 Juba flood anomaly stands out as a unique event: and the harmonic is not strong between rivers through the mid-1980s, due to fluctuations of the Shabelle then.



Luuq – Mean Normalised Anomaly of Flood Peaks



Belet Weyne - Mean Normalised Anomaly of Flood Peaks

can contribute considerable runoff (typically less that 100 cumecs) during local rainfall. Altitude 134 m amsl.

Mahaddey Weyne
Was an important station for operation of Jowhar Offstream reservoir and SNAI sugar estate. Approximately 2 days lag from Bulo Burti but can be longer during flood events. Main spillage upstream of station occurs in region of Duduble flood relief canal. Little irrigation in the reach Bulo Burti - Mahaddey Weyne. Flows at station always in-bank. Bank full flow was approximately 140 cumecs until 1979, then 164 cumecs after commissioning of the Jowhar Offstream reservoir. Altitude 105 m AMSL.

Balcad
Operated until construction of Balcad barrage (in 1979 approx). Well defined rating. Data intermittent but of good quality. Approximately 2 days lag from Mahaddey Weyne. Considerable irrigation in region of Balcad. Flow always in-bank; bank full flow approximately 95 cumecs.

Afgoi
Nearest station to Mogadishu. Data quality generally good. Between 1980 and 1990, low flows were affected by releases from Jowhar Offstream reservoir. Low flows also show weekly cycle (since 1987 approx) due to irrigation abstractions upstream. Approximately 3 days lag from Mahaddey Weyne. Flow always in-bank; bank full flow approximately 95 cumecs. Flood spillage occurs mainly in the reach Mahaddey Weyne - Balcad. Altitude 77m amsl.

Audegle
Lower-most station on the Shebelli. Data quality rather poor. Rating was affected by mid 1980's by collapse or road bridge. Approximately 1 day lag from Afgoi. Low flows sometimes show same weekly cycle as Afgoi. Many small-scale irrigation schemes in reach Afgoi - Audegle. Flow always in-bank; full flow approximately 82 cumecs. Altitude 70m amsl.

E. Some Notes on an Innovative Approach to Rainfall Estimation in the Horn of Africa

It is widely recommended that a rainfall monitoring system for early warning should integrate:

- **Qualitative information on rainfall (reported by field monitors).**
- **Seasonal forecasts if they exist.**
- **Rainfall from station data.**
- **Rainfall estimates using remote sensing (satellite data).**

Qualitative estimation is a useful way of generalising rainfall characteristics. An obvious problem with qualitative observations is that the institutional memory is limited, and is probably biased towards extreme events. Qualitative observations also provide opportunities for subjective reporting, (ie. political capital and gain).

Seasonal forecasts are readily available from global and regional meteorological services. They are useful in preparation for seasonal extremes, but are of limited value when extreme events happen.

By far the most valuable data is good quality gauge data (direct point measurement) correlated with remotely sensed rainfall estimates (integrated spatial measure).

Historic rainfall data is widely available for both the Ethiopian and Somali catchments, and FAO maintain a reasonable archive. There is limited variance between most data holdings, depending on the primary sources at hand. The advent of remotely sensed estimates in the 1990s has led to discontinuities within data sets, with correlation between them not always clear. For example the NOAA data set used in FEWS modelling, has a long term mean based on interpolated rain-gauge data from 1920 to 1980, whereas the short term mean is based on satellite derived estimates from 1995 to present day. In contrast WMO shift their mean on a 30 year bias (1961-1990, 1971-2000, 1981-2010), which is problematic where large gaps in data runs occur.

Real time rain-gauge data from Somalia is currently of little value. The aim of some agencies (including FSAU and FEWS) is to improve the data quality and flow time, so that improved precision in early warning and assessment can be achieved, deserves support.

Satellite derived rainfall estimates over Somalia are based on Thermal Infrared Imaging techniques. Calibration is a problem common to all TIR based methods of rainfall estimation in that cloud top temperatures only relate indirectly to rainfall, there being no information on the detailed variation in rainfall pattern below the cloud. Therefore for rainfall estimates to be meaningful a significant amount of averaging must take place. However, although rainfall amounts averaged over large time periods or areas may be adequately estimated, localised intensity variations are not well represented; in particular, heavy rainfalls are often underestimated (Bonifacio *et al* 1990).

The algorithm for processing TIR data is primarily based upon cold cloud duration (CCD). A preliminary estimate of accumulated precipitation is made based on the GOES Precipitation Index (GPI) algorithm (Arkin *et al* 1987). The GPI assumes a linear relationship between precipitation and CCD (with cold defined to be 235K or lower) and assumes that 3 mm of precipitation occurs for each hour that cloud top temperatures are measured to be less than the 235K threshold. It can be seen that this estimate is generalised, and not particularly accurate.

Satellite derived rainfall estimates are therefore generally calibrated by a spatial correlation of ground rain-gauges linked into the Global Telemetric System (GTS). The GPI estimate is corrected using a bias field that is calculated by incorporating the GTS observational data and fitting the biases to a grid using optimal interpolation (ie. reduction of cost functions) producing an estimate of convective rainfall. When averaged over time the product is a final estimate of total accumulated precipitation, with a new rainfall estimate generated every 10 days (Kousky *et al*, 1997).

Analysis of Sub-Saharan rainfall has led to the adoption of broad calibration zones (eg. by FAO ARTEMIS), which agree with the uniqueness of rainfall for the East Ethiopian and Somali regions (Hutchinson and Polishouk 1989). The calibration problem for the Somali regions is that there are very few reliable zonal gauges, and there are none in Somalia linked into the GTS. This may be partly resolved by the use of statistical algorithms for precipitation estimation.

Rain-gauge data are only valid for a small area in proximity to the gauge and can be considered as observation at a point. On the other hand satellite data are integrated values for the entire surface covered by the instantaneous field of view of the sensor (eg 5km for METEOSAT) (Flitcroft *et al* 1989). The incompatibility in the spatial representation can be solved through the use of geo-statistical techniques such as block kriging (Journel and Huijbregts 1978) to merge satellite and rain-gauge data. Specific drawbacks of merging satellite and rain-gauge data are in assuring the spatial and temporal stability of the calibration coefficients.

Merging of Satellite and Rain-gauge Data

Errors associated with these problems may be reduced by spatial and temporal modulation over defined pixels. The calculation of pixel average rainfall estimates can be carried out using block kriging (Journel *et al* 1978) and a single estimate can be combined where gauge based and satellite based rainfall estimates have the same spatial support (ie. the satellite pixel or $5km^2$ for METEOSAT). Grimes and Bonifacio (1998) developed a merging routine for Southern Africa Drought and Flood Warning. It is reproduced here as the basis for an algorithm within the Horn Early Warning system.

Optimal merging of data sets requires the calculation of pixel average values, with each contribution weighted according to the inverse of its associated error. The variance is thus a simple addition of the independent mean square errors associated with the satellite and gauge estimate for any given pixel. Given that the total variance and kriging error increase with rainfall, the optimum pixel estimate and its associated error can then be calculated from modelling a given mean rainfall per unit pixel area, ie.

Areal Rainfall Estimation from Rain-gauge Data

The mean rainfall P_i over the *i*th satellite pixel with centre at position $\mathbf{x}_i$ and with area $B(\mathbf{x}_i)$ is the variable of interest:

$$P_i = \frac{1}{B(x_i)} \int_{B(x_i)} P(x)dx \qquad (1)$$

The value of P_i is estimated by block kriging as a linear combination of the point observations at the rain gauges:

$$P_{gi} = \sum_{j=1}^{n} \lambda_j P(x_j) \qquad (2)$$

where P_{gi} is the estimate of P_i and $P(\mathbf{x}_j)$ is the observed rainfall for gauge *j* at position x_j.

The weights λ_j are optimal in the sense that they provide unbiased estimates and they minimise the estimation variance. The weights are obtained as solution to the block kriging system:

$$\sum_{j=1}^{n} \lambda_j \gamma_p(x_k, x_j) + \mu = \gamma_p(x_k, B(x_i)) \qquad \text{with } k = 1,\ldots,n \qquad (3)$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

and the estimation variance is given by

$$e^2_{gi} = \sum_{j=1}^{n} \lambda_j \gamma'_p(x_k, B(x_i)) + \mu$$

(4)

where μ is a Lagrange multiplier, $\gamma_p(\mathbf{x}_j, \mathbf{x}_k)$ is the rainfall variogram function between points $\mathbf{x}_j$ and $\mathbf{x}_k$, and $\gamma'_p(x_j, B(x_i))$ is the mean rainfall variogram function between point $\mathbf{x}_j$ and pixel i with area $B(\mathbf{x}_i)$).

e_{gi}^2 is an estimate of the mean square error associated with P_{gi}.

The variogram $\gamma(\mathbf{x}_j, \mathbf{x}_k)$ describes the variation of the correlation of the rainfall field with distance, defined as

$$\gamma(x_j, x_k) = \gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} (P(x_i) - P(x_k))^2$$

(5)

where $\boldsymbol{h}$ is the vector separating $\mathbf{x}_j$ and $\mathbf{x}_k$ and $n(\boldsymbol{h})$ is the number of gauge pairs with separation vector $\boldsymbol{h}$.

Thus where gauges are sufficiently close that their observed rainfalls are well correlated, γ has a small value. Where the gauges are further apart, γ is larger and will eventually reach a limiting value equal to the spatial variance of the field. The inclusion of γ in equations (3) and (4) mean that both the rainfall estimate and their associated errors take account of the distribution of the gauges relative to the spatial structure of the rainfall.

Satellite Gauge Merging

As previously stated optimal merging of data sets requires the calculation of pixel average values, with each contribution weighted according to the inverse of its associated error. Thus for any pixel *i*, the optimum estimate P_{oi} is given by

$$P_{oi} = \frac{e^2_{si} P_{gi} + e^2_{gi} P_{si}}{e^2_{si} + e^2_{gi}}$$

(6)

and the associated error is given by

$$e_{oi} = \frac{e_{si} e_{gi}}{\sqrt{e_{si}^2 + e_{gi}^2}}$$

(7)

where e_{si}^2 and e_{gi}^2 are the mean square error associated with the satellite estimate and the gauge estimate for the pixel. e_{gi} is obtained from equation (4). To evaluate e_{si} a scatter plot of pixel rainfall derived from CCD against pixel rainfall derived from rain-gauges is required. The scatter of points is due to both e_{si} and e_{gi}. As these are independent the total variance is simply:

$$e^2_{\mathrm{i}} = e^2_{\mathrm{si}} + e^2_{\mathrm{gi}}$$

(8)

It cab be seen that the final relation is such that e_i^2 and the kriging error both increase with rainfall. Therefore, both these relationships can be modelled so that for a given P_i, e_i^2 and e_{gi}^2 can be calculated, leaving e_{si} to be obtained from equation (8). P_{oi} and e_{oi} can then be calculated via equations (6) and (7).

The technique is important since it has subsequently been shown that the satellite-gauge merging process gives very promising results. The merging process automatically gives the gauge data an appropriate weighting dependant on gauge density, and will general produce estimates that are better than other methods such as satellite estimates, or kriging with external drift (Hudson *et al* 1994).

But what does this mean for Somalia and the Horn of Africa?
The implication of this thinking is that

1. **Where a gauging system is being set up to provide input to an early warning system, the emphasis is better directed to a dense small area "calibrating network", rather than a regional spread of independent gauges.** This is for the technical reasons described, and for ease of managing the data set, and is especially the case where the quality of data from independent gauges is poor and transmission times are uncertain (as is the case in Somalia). If at some time in the future rain-gauges can be re-established at the pre-war GTS sites then the calibration is doubly strengthened.

2. **A dense area calibrating network implies a project and project site to make it work. The project should integrate opportunities for adaptive research by FAO, including FSAU and AFRICOVER in crop production and environmental science.** A suitable pilot site could be Gabiley in Somaliland for the following reasons.

   a. Long term pre-war rainfall records from a gauge linked into the GTS provide opportunities for temporal correlation.

   b. The coefficient of inter-annual variation of rainfall in Gabiley is 33%. This is precisely the threshold proposed for transition from the equilibrium to non-equilibrium state in rangeland ecology (ie. the point at which rainfall begins to drives the ecological system). Monitoring of agricultural and agro-pastoral production over time, in relation to spatially integrated rainfall observation, therefore provides an excellent opportunity for adaptive research into food security and eco-system dynamics

   c. There is a peaceful record in Gabiley over the past few years and every chance of this continuing. Numerous development project have been completed, including a cadastral survey. A significant amount of baseline data already exists which would be beneficial in establishing a rain gauge field and a pilot study into agricultural production and land management. The site could easily become a pilot "research and calibration" site also for FSAU and AFRICOVER projects.

D. Hydrologic characteristics of the Juba and Shabelle gauging sites

Reproduced from Final Report – Phase 3 of the Hydrometric Project. The principal gauging stations are shown in the figure 4.

D.1 Juba Gauging Stations

Lugh Ganana
Uppermost station on the Juba. Well defined rating. Peak recorded flow approximately 1800 cumecs. Altitude 143m amsl.

Bardheere
Station on mid Juba. Approximately 2 days lag from Luuq but possibly slightly longer during flood events. Peak recorded flow approximately 1800 cumecs. River valley well defined in reach Luuq - Bardera so spillage losses small except during exceptional floods. Little irrigation in reach. Several tributaries flow into reach; these are normally dry but can contribute considerable runoff (several hundred cumecs) during local rainfall. Altitude 89 m amsl.

Kaitoi
Station first established in 1963 but only operated for two years, it was re-established in 1972. Data generally of good quality but, since 1980, of no value for discharge due to construction of Fanoole barrage a short distance downstream. Approximately 3 days lag from Bardera. Flow always in-bank; bank full flow approximately 660 cumecs. Little irrigation in reach Bardera - Kaitoi. Main spillage in reach occurs shortly upstream of Katoi.

Mareere
Station established in 1977 and operated by Juba sugar project. Data of excellent quality but rating uncertain at high flows. Bank full flow approximately 625 cumecs. Much of the reach Katoi-Jamaame protected by flood bunds. Approximately 4 days lag from Bardera. During 1980s, flows affected by abstractions by Fanoole irrigation project. Altitude 14m amsl.

Kamsuma
Station established in 1972 by the Russian Selchozpromexport project and operated for 4 years. Re-established in 1988 by the Somalia Hydrometry Project. Flow always in-bank; bank full flow approximately 510 cumecs. Data generally of good quality. Affected by pumped abstractions by Juba sugar project and other smaller schemes.

Jamaame
Lower-most station on the Juba. Established in 1963 but only operated intermittently since then. Flow always in-bank; bank full flow approximately 480 cumecs. From mid 1980's spillages upstream reduced by Mogambo flood relief canal & low flows affected by pumped abstractions from Mogambo irrigation scheme. Exceptionally, flows may be affected by drainage from the catchment of the lower Shebelli and by return flows from old river channels of the Juba. Possibly some tidal influence at the station as it is at sea level.

D.2 Shabelle Gauging Stations

Belet Weyne
Uppermost station on the Shebelli. Well defined, stable rating for in-bank flows. Flood plain several kilometres wide so flood flows passing Belet Weyn can be considered greater than indicated by rating. Peak recorded flow approximately 500 cumecs from rating, but actual peak flow estimated to be about 1400 cumecs. Altitude 176 m amsl.

Bulo Burti
Important station for monitoring progress of floods. Approximately 2 days lag from Belet Weyne whilst flow in bank, but much longer during flood events. Flood plain in reach Belet Weyne - Bulo Burti bounded by low hills so much of spilled flow returns as flood subsides. Little irrigation in reach. Several minor tributaries flow into reach; these are normally dry but

Annex C

Projects Bibliography and Materials

The bibliography provides a preliminary list of documents associated with projects and studies in the Juba and Shabelle rivers. It is not exhaustive. Where "Reports Series" is used a series of reports is available, in which case the year given is an average value for the project or study.

1. **Agriculture in Regions along the Shebelli** (1989) *M. Khalif & H. Ismail*: Istituto Agronomico Per L'Oltremare-Firenze.

2. **Baardheere Flood Detention Reservoir - Reports Series (1979)** *Technital S.P.A./ Technosynesis S.P.A Rome:* Somali Ministry of Public Works

3. **Baardheere Dam Project - Reports Series** (1988) *China International Consulting Corporation:* Somali Ministry of Planning and Juba Valley Development

4. **Bakool & Gedo Regions: Pilot Agricultural Development Project - Reports Series** (1988) *Sir M. MacDonald & Partners Ltd:* Somali Ministry of Agriculture

5. **Dara Salaam Busley Agricultural Development Project - Reports Series** (1988) *Sir M. MacDonald & Partners Ltd:* Somali Ministry of Agriculture

6. **FAO and Agriculture Development in Somalia** *M.K. Shawki:* FAO.

7. **FAO - Towards a Strategy for Agricultural In Somalia** *FAO:* FAO.

8. **Farahaane Irrigation Rehabilitation Project - Reports Series** *(1988) Sir M. MacDonald & Partners Ltd:* Somalia Ministry of Agriculture

9. **Farjano Settlement Project - Reports Series** (1985) *Sir M. MacDonald & Partners Ltd:* Somali National Refugee Commission/UNHCR

10. **Flood Damage Assessment Study - Reports Series** (1981) *Sir M. MacDonald & Partners Ltd, Hunting Technical Services Ltd:* Somali Ministry of Agriculture/FAO

11. **Genale - Bulo Marerta Project - Reports Series** (1978) *Sir M. MacDonald & Partners Ltd:* Somali Ministry of Agriculture

12. **Homboy Irrigated Settlement Project - Reports Series (1980)** *Sir MacDonald & Partners Ltd, Hunting Technical Services Ltd:* Somali Settlement Development Agency

13. **Homboy Area and Smallholder Banana Cultivation in the Lower Juba Valley and Assessment of Agricultural Benefits - Reports Series (1987)** *Sir M. MacDonald & Partners Ltd:* Somali Ministry of Planning and Juba Valley Development

14. **Hydrometry Project, Somalia - Reports Series** (1990) *Sir M. MacDonald & Partners Ltd, Institute of Hydrology, UK Overseas Development Administration:* Somali Ministry of Agriculture

15. **Country Report on Traditional Storages and Reserves at Different Levels for IGADD Sub-Regional Project on Traditional Storages and Food Reserves for Food Security Improvement (1989)** *A. A. Odawa, M.A. Osman:* IGADD

16. **Reconnaissance and Pre-Feasibility Studies in Jalalagsie and Jowhar districts and Gedo Region** (1980) *Sir M. MacDonald & Partners Ltd*: Somali National Refugee Commission

17. **Jowhar Offstream Storage Project - Reports Series** (1980) *Sir M. MacDonald & Partners Ltd*: Somali Ministry of Agriculture

18. **Jowhar Sugar Estate Drainage and Reclamation Project - Reports Series** (1978) *Sir M.MacDonald & Partners Ltd*: Somali Ministry of Industry

19. **The Giuba River Scheme Section 1** (1965) *Selchozpromexport*: Somali Republic

20. **Masterplan for Juba Valley Development** (1989) Somali Government

21. **Irrigation Drainage and Salinity Problems in the Juba Valley** (1993) *M. A. Hussein*: Rivista di Agricoltura Subtropicale e Tropicale

22. **Juba River Valley Development Study - Reports Series** (1986) *Technital S.p.A* Somali Government

23. **Juba River Valley Hydrology Intermediate Report** (1983) *A.GRAR - UND Hydrotechnik GMBH:* Somali Ministry of Juba Valley Development Federal Republic of Germany

24. **Juba Sugar Project Kamsuma North Area and Labadaad South Area Irrigation and Drainage Works – Reports Series** (1978) *Sir M.MacDonald & Partners Ltd* Jubba Sugar Project Inc

25. **Middle Shabelle Flood Control Study – Reports Series** (1995) *Mott MacDonald & Partners Ltd.* EC. Somalia Unit

26. **Mogambo Irrigation Project – Reports Series** (1979) *Sir M.MacDonald & Partners Ltd* Somalia State Planning Commission. Kuwait Fund for Arab Economic Development

27. **Qoryooley Irrigated Refugee Farm Reports Series** (1984) *Sir MacDonald & Partners Ltd:* Save the Children (USA). Somali Democratic Republic

28. **Saakow Dam, Juba River – Reports Series** (1978) *Sir. MacDonald & Partners Ltd:* Somali State Planning Commission

29. **Surface and Underground Water Resources of the Shebelli Valley** (1964) *C. Faillace:* Somali Ministry of Public Works

30. **Project of the Water Control and Management of the Shebelli River – Reports Series** (1969) *FAO. Hunting Technical Services Ltd. Sir M. MacDonald & Partners Ltd:* UNDP

31. **Shebelli River Water Salinity** (1995) *M. Falciai. M. A. Hussein. N. Simonelli:* Rivista di agricoltura Subtropicale Tropicale

32. **Studio della Variabilita delle portate dell'Uebi. Shebeli in Somalia** (1995) *S. Vanella:* Rivista di agricoltura Subtropicale Tropicale

33. **Upper Juba Catchment Development Review** (1987) *Sir M.MacDonald & Partners Ltd:*

34. **Water for Life** (1994) *FAO:* FAO

35. **Study on Water Points in Gedo and Bakool Regions – Reports Series** (1989) Salzgitter Consult GMBH.German Water Engineering

USGS
science for a changing world

INTERNATIONAL PROGRAM
at the EROS Data Center

FEWS FLOOD RISK MONITORING IN EAST AFRICA

USGS EROS Data Center, Science and Applications Branch, International Program

Regional flooding is directly relevant to humanitarian assistance and sustainable development goals of USAID in East Africa. Flooding in its most immediate form can create a need for disaster relief by inundating farms and villages and disrupting transportation networks, ultimately affecting market distribution systems.

Following major flooding as a result of El Nino in 1997, USAID and other international agencies responsible for food security in East Africa needed an appropriate way to assess flood risk in the region. Most of the resources had previously been directed towards drought monitoring activies as part of USAID's Famine Early Warning System (FEWS). The FEWS Flood Risk Monitoring project for East Africa was developed in September of 1998 to provide up-to-date information about the risk and extent of flooding at key locations in the region.

Currently, a hydrologic model is being developed for a pilot basin in Kenya (Nzoia River) that flows into Lake Victoria. Spatially distributed input to the model includes NOAA (Climate Prediction Center) estimates of daily rainfall totals, USGS-developed global land cover, and 1-kilometer digital elevation model and derivative datasets developed for hydrologic applications (HYDRO1K), and FAO soil layer at 1:1,000,000 scale. The results from the Nzoia River model will be used to develop a flood risk model for other important river basins and key monitoring locations in the region. Real-time plots of streamflow and maps

displaying the risk of flooding within a given river basin will provide useful information to organizations concerned with food security and disaster relief in the Greater Horn of Africa. Contact info: James Verdin (605-594-6018, verdin@edcmail.cr.usgs.gov); John Dvorsky (605-594-6064, dvorsky@edcmail.cr.usgs.gov); Guleid Artan (605-594-6195, gartan@edcmail.cr.usgs.gov).

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U.S. Geological Survey
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Maintainer: webmaster@edcintl.cr.usgs.gov
Last Updated: Tuesday, **May 11, 1999**

Mozambique Flood Information Stream Flow Model Flood Risk Map Page

This is an interactive map. At the top is a list of map tools. You must select a map tool to interact with the map. Zoom In will allow you to click on the map and view an area in more detail. The Pan functions will move the map in the indicated direction. Restart Map will start the map at the begining again. Identify will allow you to query a specific map point, and interact with the data used to create the map.

Date of Stream Flow Calculations currently shown: 3/8/01
Date Stream Flow Calculations were generated: 3/8/01

Map Reference Data: Select Theme to Change Map Extent of Feb/Mar 2000 Flood:
Hide the Flood Zone

Stream Flow Model (SFM) Data: 3/8/01 Basin Flood Hazard

The Stream Flow Model (SFM) calculates the stream flow at basin outlets using an image of Rainfall data. The actual calculations are done for an entire watershed basin at the basin's lowest point (outlet). By default the map above shows basins color-coded rather than outlets, because the basins are much easier to see. You can change this representation to show Basins or Streams color coded.

Several types of reference data are available to help you locate particular areas of interest. This includes 1997 Census data, and some basic landcover information, in addition to roads, rivers, water bodies, cities. How to use this map:

> This model estimates the stream flow at the outlet, and compares this to historical estimates of stream flow at the outlet to achieve a relative indicator of the probability of flooding. The basic usage of this map, is to zoom in (Magnifying glass button and clicking on the map) to an area of interest, near a city or some other reference, and then change to the hydrograph (Miniature Graph Button and clicking on the map). This will produce a hydrograph window that shows the stream flow estimated from the model for the current year.

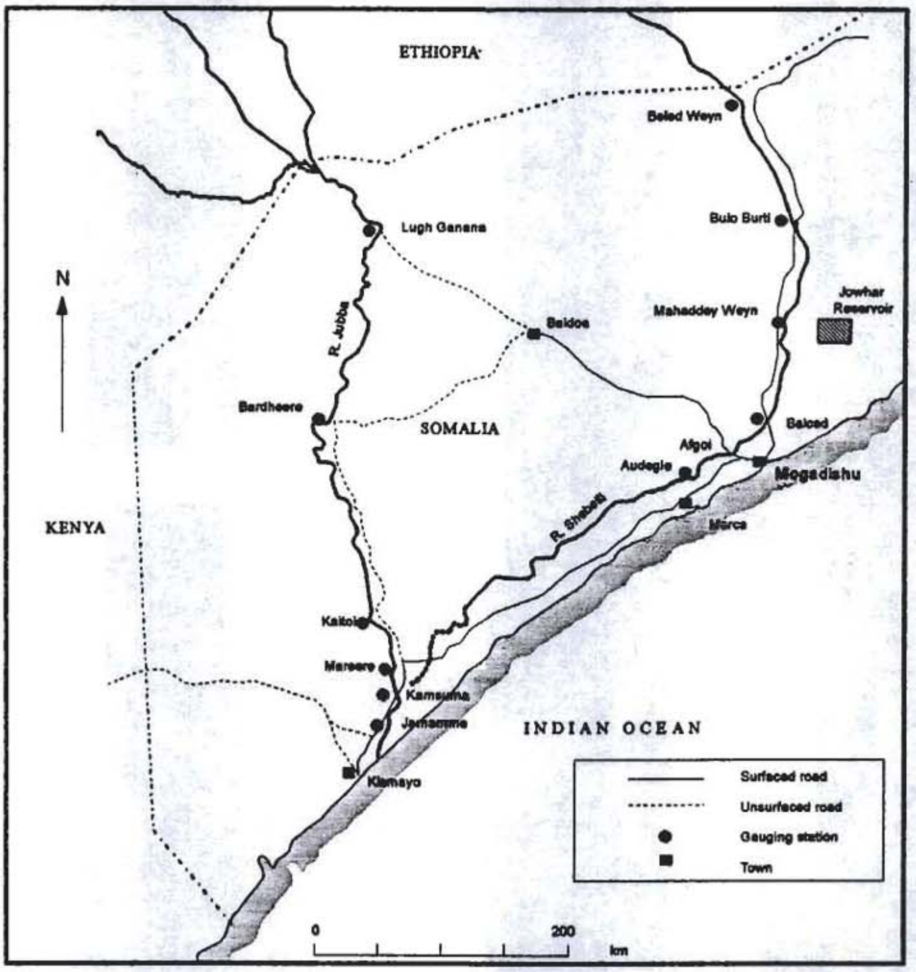
DAILY MEAN — 1950's — 1990.

Institute of Hydrology

Project Experience

Hydrometry Project, Somalia

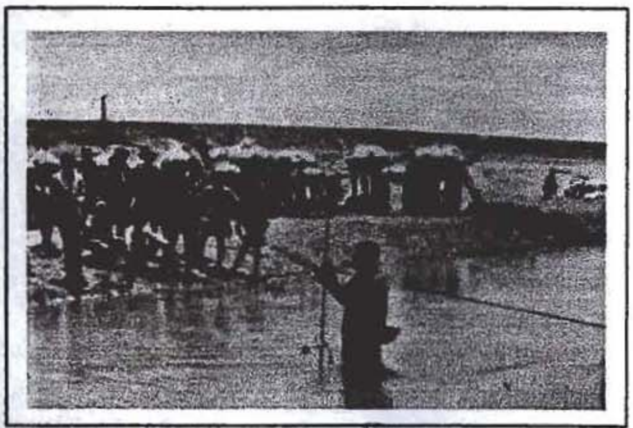
Location: Somalia
Client: Water Department,Ministry of Agriculture .Somalia
Funding Agency: UK Overseas Development Administration
Date of study: 1984 - 1990



The Institute of Hyrology was responsible for a hydrometric study and the development of a database system for the storage and processing of hydrological data in Somalia. On-site training in the use of the system was provided for local staff. Flow forecasting models were developed for the rivers Jubba and Shebelli.

This project was set up to review and update the whole hydrometric network and data processing procedure for Somalia. The project lasted from 1984 to 1990 and was performed in association with Mott MacDonald Ltd. All the existing flow gauging stations, which are confined to the Jubba and Shebelli rivers, were inspected. Advice was provided on suitable equipment to be installed, including the provision of automatic data loggers. Sites for new stations on the Jubba and Shebelli were chosen, and the installation of the stations was supervised.

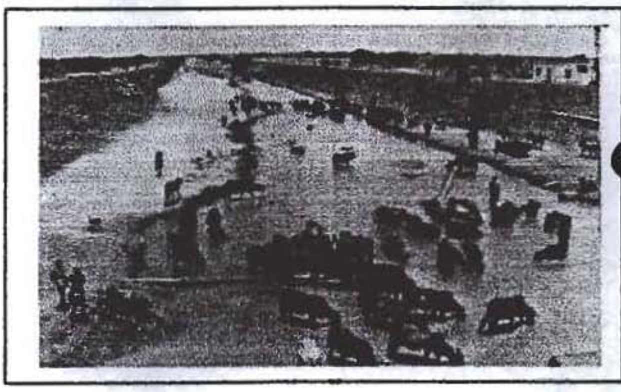
Data processing procedures were examined in detail and new procedures were recommended, including the provision of a micro-computer and a hydrological database system, HYDATA, which was developed, in the first instance, especially for this project. All the historic river level records for the Jubba and Shebelli were transferred to HYDATA, which provided some preliminary data checking in the process.



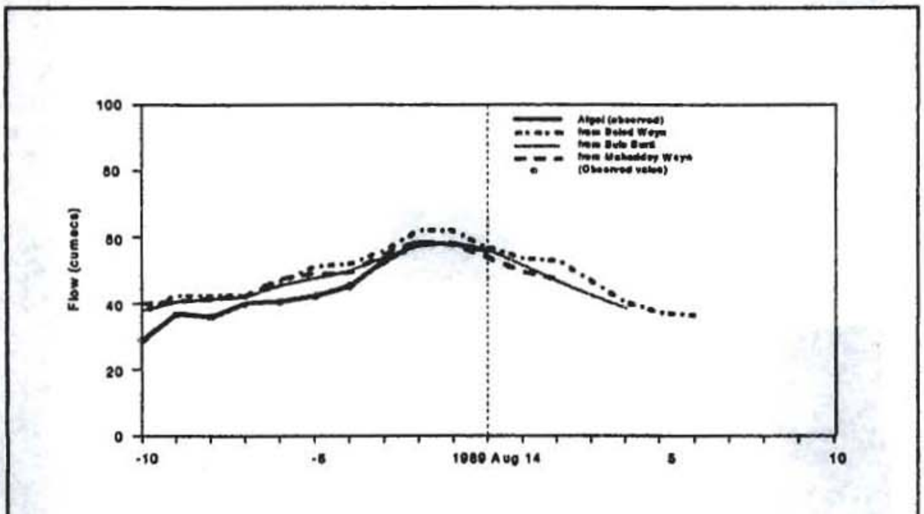
Training in river flow gauging techniques

HYDATA was then used to develop new rating curves for each site and additional current meter measurements were carried out where necessary. Levels were then converted to flows using HYDATA. The final checking and infilling of the flow data was performed using a simple river simulation model developed during the project. This work led to the publication for the first time of a hydrometric databook for Somalia. Local staff were also trained in hydrometric analysis techniques and in the use of the HYDATA system.

In the later stages of the project, a flow forecasting model was developed for use on the Jubba and Shebelli. Correlation and flow routing techniques were used to model the river flows. Forecasts of up to one week ahead could be obtained based on radio data received from the gauging stations nearest the Somalia/Ethiopia border. For the Shebelli, a simulation model for the Jowhar Offstream Storage reservoir was also included in the forecasting model, and was used to assess the performance of the reservoir since it was first commissioned.



Canal intake for Jowhar reservoir

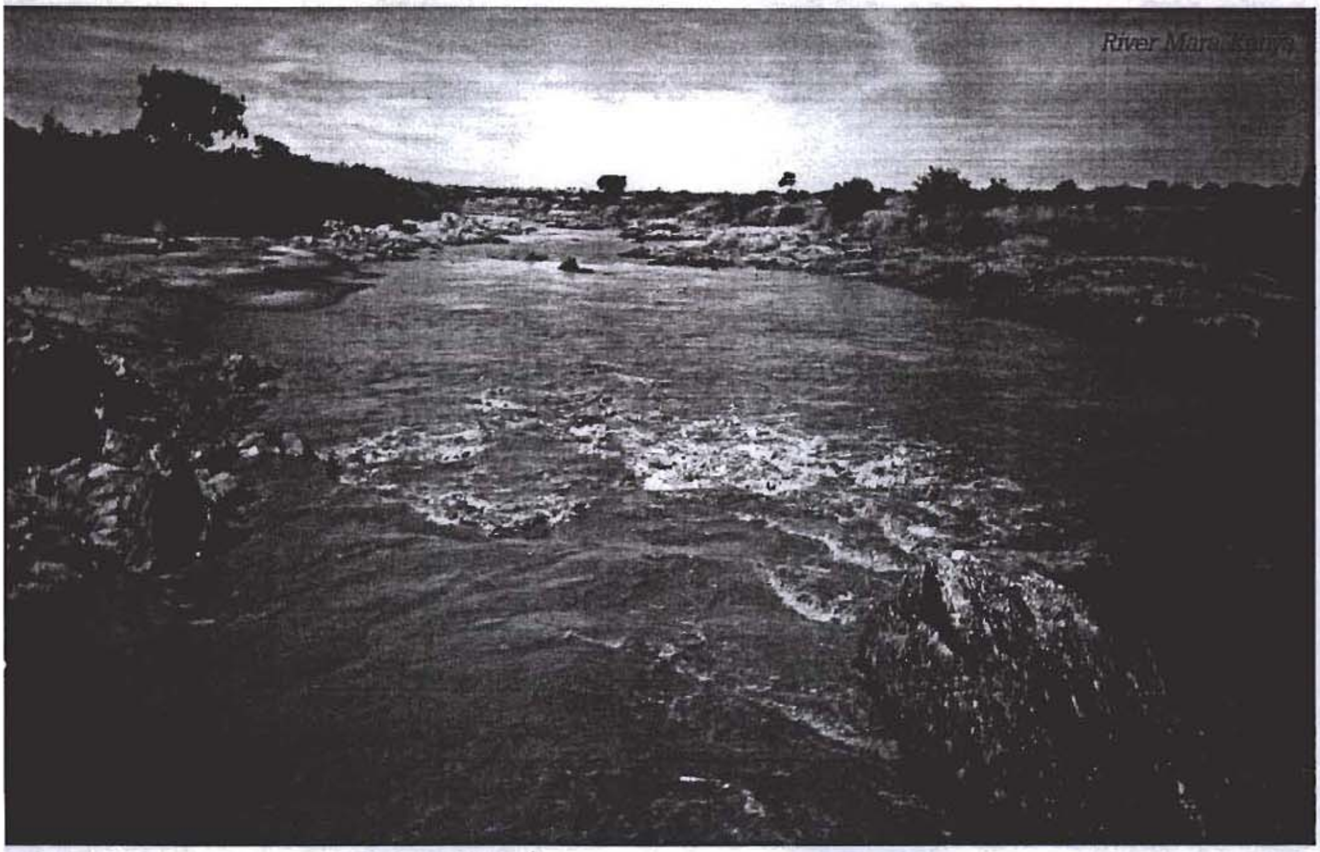


Example flow forecast based on observations further upstream

Institute of Hydrology

HYDATA

Hydrological database system



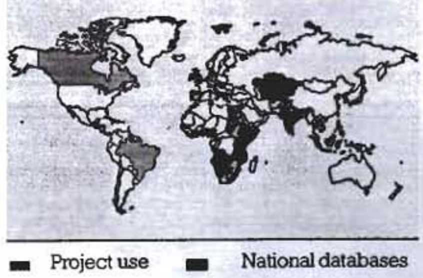
River Mara, Kenya

HYDATA is a PC-based hydrological data processing and analysis system.

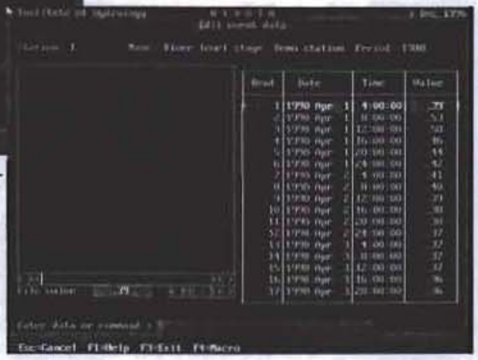
The software has been developed by hydrologists and draws on the extensive experience of the Institute of Hydrology in hydrological and water resources studies in the UK and worldwide.

HYDATA is currently used in over 40 countries, including 25 where it is used as the national hydrological database system.

Worldwide HYDATA use (1997)



Data editor



Fit rating (in French)

Data held

- **Station location**
  Latitude / easting, longitude / northing, altitude.
- **Station details**
  Name and number, river basin area and number.
- **Event data**
  River level, rainfall, lockage, lake/reservoir level. Up to 100 readings per day.
- **River gauging data**
  Date, stage, velocity, area, discharge.
- **Rating equations**
- **Discharge/flow**
- **Rainfall**
- **Lake or reservoir storage**
- **General time series data**
- **User-defined daily or monthly data** (e.g. evaporation, temperature, electrical conductivity).

Data types

HYDATA has been designed to handle the types of data most often encountered in hydrological and water resource studies and is used by a growing number of consultants, water authorities and government organisations.

Both daily and monthly data can be stored. Daily flow and storage data may be calculated automatically using stored rating equations.

Rating equations

In hydrological studies, it is often necessary to develop rating equations giving the relationship between river level and discharge, or between the water level of a lake (or reservoir) and its storage. HYDATA allows rating equations to be derived quickly and accurately from measured data.

The rating equations used by HYDATA are logarithmic in form. They can have up to three segments, each station having up to 20 rating equations, (or alternatively six segments, each station having up to 11 rating equations). The raw data required to develop a rating are entered using HYDATA's gauging editor.

Rating equations can be entered directly, if available, or can be derived using the interactive graphics facility provided. A 'best fit' rating equation can be calculated if required.

Key features

- Data can be entered via the built-in data editor (with graphics display), or from a file.
- Context sensitive help.
- Database security and integrity functions.
- Available in English, French, Spanish and Portuguese. Other language developments are possible.

Comparison plots

Double mass plot

- compares two daily time series to determine the integrity of data by comparing cumulative totals at two stations.
- allows analysis over any time period to determine an identified shift and to highlight periods of missing data.

Time series plot

- plots one or two stations of daily data superimposed or separated.
- can be over a selected period, allowing lag of one series relative to another.
- offers choice of linear or logarithmic axes.

Flow duration

- for up-to five daily flow stations simultaneously presented as a curve or a table.
- table of class intervals and percentage of data in each class.
- logarithmic class intervals and plot options.
- with user-selected time base and period.
- allowing seasonal analysis according to months.
- with 5, 10, 25, 75, 90, 95 percentile flows interpolated.

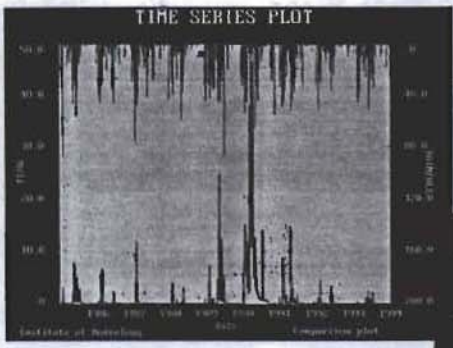
Low flow analyses

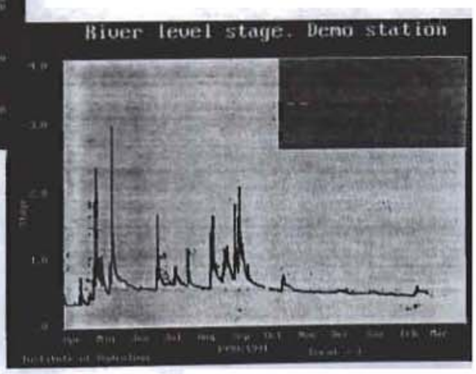
Baseflow index

- automatic baseflow separation is carried out on daily data giving total and baseflow separation, runoff volumes over any selected period of data and the ratio of total flow to baseflow.
- includes option to plot or print total and separated hydrograph.
- provides printed analysis summary giving total and baseflow volumes for the separation period and each hydrological year.

Logarithmic plot

- determines recession slope for a master recession curve (used in low flow forecasting or inter-basin comparison).
- supplies abstracts of data over any time period.
- specifies x-axis in terms of days from the start date to assist with calculation.
- identifies periods of suitable recession without the need to extract data.





Sample output from HYDATA

Hydrograph recession plot

- plots a period of hydrograph recession as flow today against flow 'n' days previously.
- can be analysed to estimate the recession constant.

Low flow frequency analyses

- Annual low flow frequency analysis giving low flow return periods.
- Variable time base for analysis.
- Standardisation option for producing non-dimensional curves.
- Calculation and plotting using the Weibull distribution.

Data output

Stored data can be displayed using HYDATA's graphics and printing facilities. Graphs can be viewed on screen or printed and can be customised for inclusion in reports. The tabulated data are suitable for use in hydrological yearbooks. Data can be output to a file for use with other PC packages.

A basic source of information for national inventories of Natural Resources

A wide variety of applications are based on land cover data. Since this basic layer will be readily available, the development of specific applications can be done at relatively low costs by combining **made** with other relevant data sources.

Since every application will be based on the standardized FAO LCCS, the development of methodologies for specific applications is essential because of the potential to apply them in different geographical locations on the same basic data.

- Direct applications on
  - Sustainable urban and industrial planning
  - National investment plans
  - **Forest** Inventory
  - Forest Management
  - Forest Monitoring
  - Firewood production

  - **Agricultural** acreage statistics
  - Basic info for crop assessment and crop yield
  - Agricultural planning + monitoring
  - Rangeland assessment
  - Green Biomass assessment
  - Grazing capacity
- Data source for **wildlife** management and animal habitats
- Basic information for domestic/wild animal disease monitoring
- Base for calibration at regional level of low resolution satellite imagery (NOAA-NDVI, MODIS, SPOT-VEGETATION)
- Basic information for **ecological** changes/trends:
  - Ecosystem definition
  - Climatic zones
  - Desertification
  - Biodiversity
- Basic resource for **hydrological** run-of models (national, regional level)
- A common regional database for future monitoring of Land Cover Changes.

AFRICOVER - *Eastern Africa*

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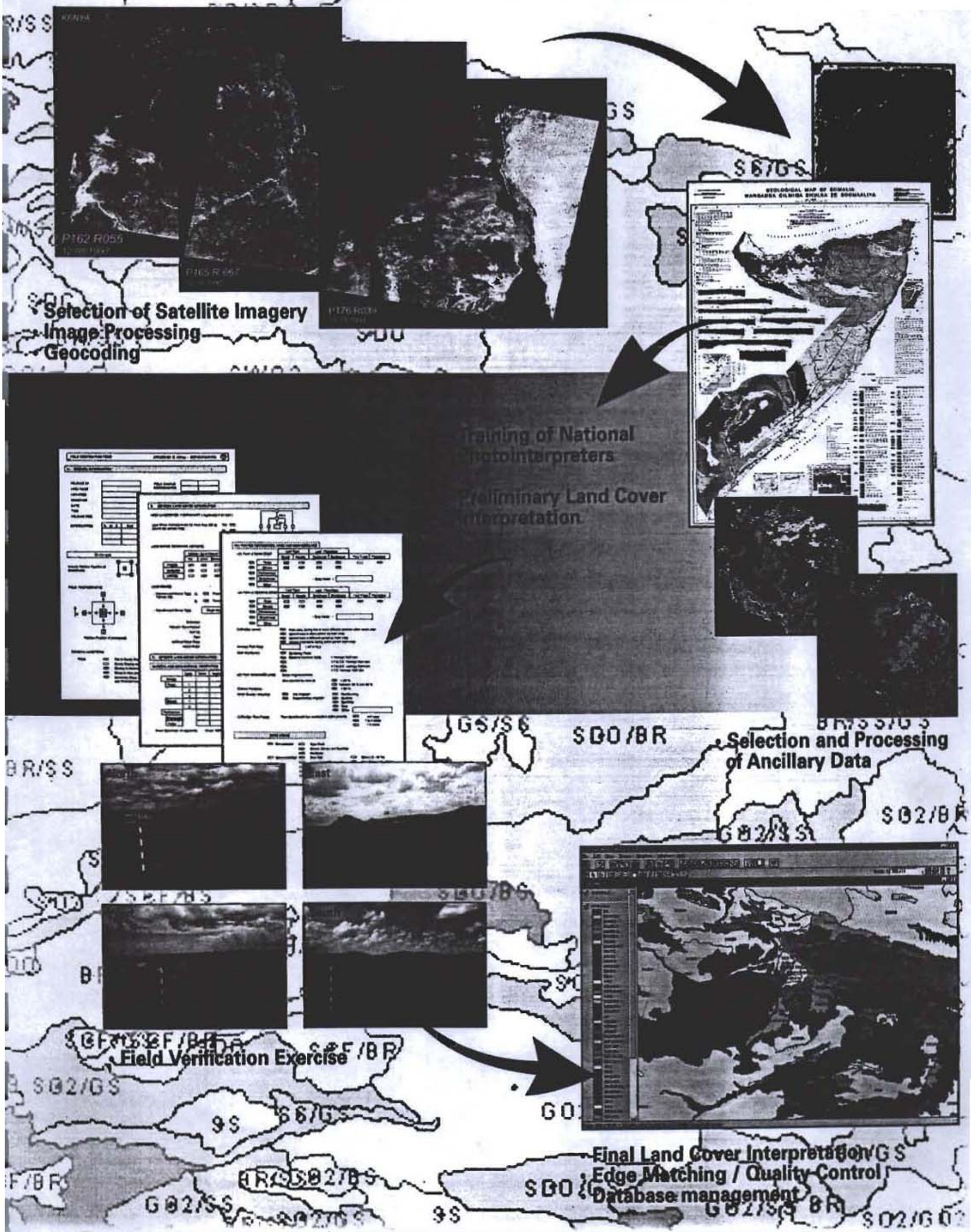
Email: info@africover.org
www.fao.org
www.africover.org

Environmental resources

AFRICOVER PRODUCTION CHAIN



AFRICOVER

EASTERN AFRICA

planning · forestry · water · rangeland · agriculture · statistics · wildlife

ultipurpose fricover atabase for nvironmental resources

New international standard for land cover classification

Improved flexibility and efficiency of photointerpretation

Powerful Updating Tool

New Tool: [illegible] and Stan[illegible] Interpr[illegible]

Exhaustive Data Explorer

First operational module of AFRICOVER initiative

Area covered = 8.5 million km^2 (almost one third of Africa)

Executed by national and international experts

Information available for national/international user community.

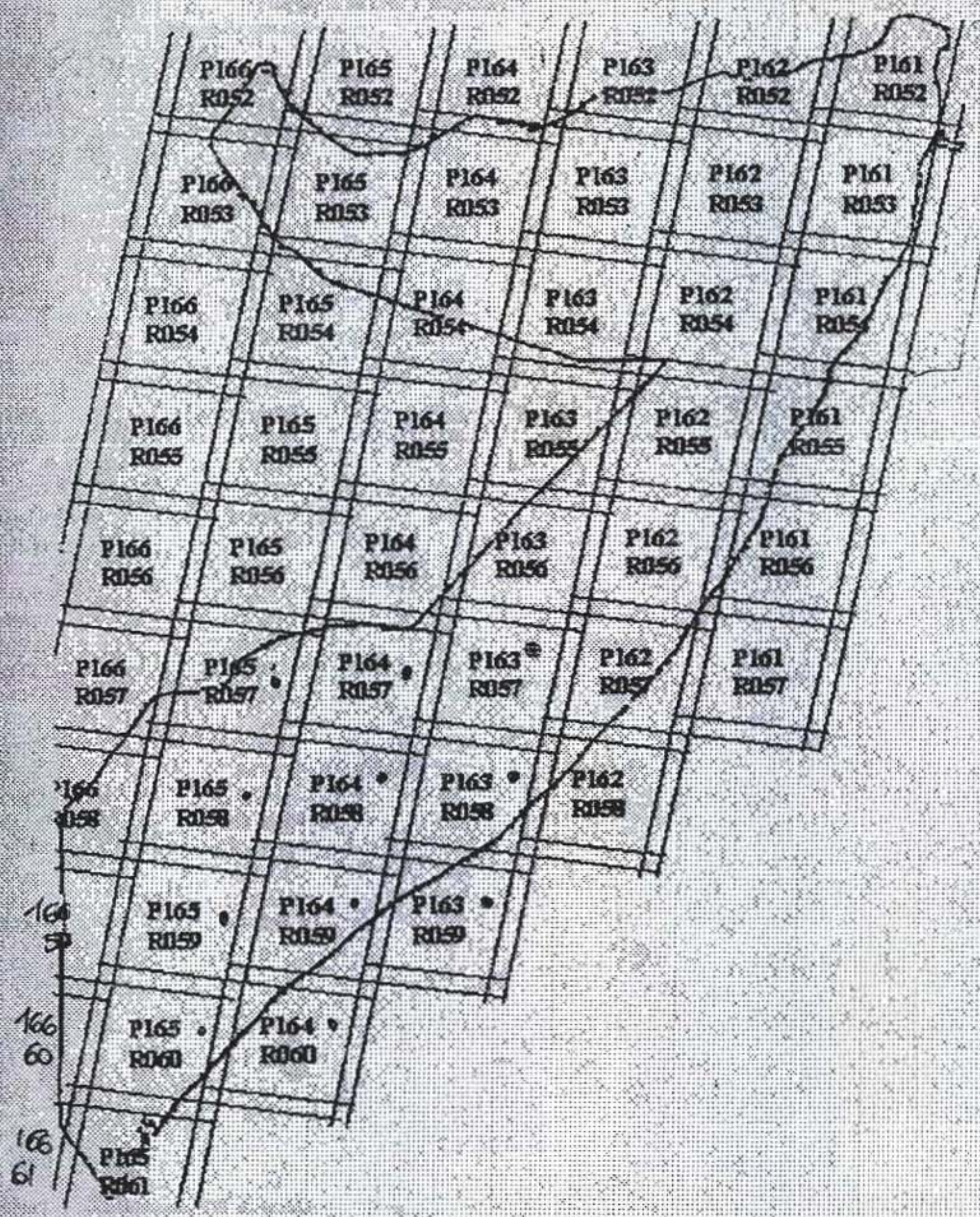


Figure 2.1 - Landsat scene coverage.