Flood Management Cluster

Kenya Cluster

NILE BASIN CAPACITY BUILDING NETWORK FOR RIVER ENGINEERING (NBCBN-RE)

Proposal for a Flood and Drought Forecasting and Early warning Program (for the Nile Basin)

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Preface

The Nile Basin Capacity Building Network for River Engineering (NBCBN-RE) was launched by the Hydraulic Research Institute (HRI in Cairo) and UNESCO-IHE, the Netherlands, with the support of the Dutch Government at the end of the year 2000. The main objective was to build and strengthen the human resource and institutional capacity in the ten Nilotic countries towards a sound development of water resources in the Nile River Basin. This is being achieved by a vision to create the opportunity for water professionals in the Nile Basin countries to have equal access to information and knowledge in a way of doing research, training, and sharing and transferring knowledge. The NBCBN-RE is a network linking professionals in the water sector. This network is placed under the umbrella of the Nile Basin Initiative (NBI). The research clusters through which training and knowledge would be transferred are as follows: River Morphology headed by Sudan; Hydropower Development by Tanzania; GIS and Modelling by Egypt; River Structure by Ethiopia; Environmental Aspects by Uganda; and Flood Management by Kenya. All the ten countries are members in various research clusters based on their interest.

The cluster on Flood Management was approved as the sixth and the last cluster in the NBCBN-RE. The cluster was adopted by Kenya and coordinated by the University of Nairobi. The countries are members following their interest; Ethiopia, Rwanda, Sudan, Tanzania and Uganda. Two workshops were organised in Nairobi. The first workshop was held between 22nd and 24th September 2003, where the scope of the project was presented and two research topics were selected after in-depth discussions namely:

- Flood forecasting and early warning and;
- Flood and catchment management.

Under these topics research teams have been formed and research coordinators elected. Research programmes have also been formulated and approved and catchments identified in the concerned countries that would serve as examples for the research.

In this research, an attempt is being made to strengthen the Flood Forecasting capacity as well as the Early Warning activities through the Nile Basin Initiative (NBI). Some of the components in a flood forecasting and early warning system that are necessary include:

- The technology to make quantitative forecasts (e.g. river flows and levels, rainfall amounts, etc.);
- A system to evaluate the forecasts and decide on a course of action (e.g. warning, evacuation, etc.);
- A system for implementing the actions (e.g. distribution and dissemination of the warning);
- A system for providing information or managing operations during the flood;
- A system for evaluating all the activities mentioned above after a flood.

Developing and setting up a system as described above will be achieved through collaboration and cooperation with relevant institutions and organization within the Nile Basin countries. For example, the Regional Institutes for Meteorological Training and Research (IMTR) will play a crucial role in generating quantitative inputs of the products from the High resolution Regional Model (HRM) currently being tested at the Kenya Meteorological Department (KMD). The Ministry of Water Resources Management and Development will be useful by providing the need for hydrological data, while the International Centre for Research on Agro Forestry (ICRAF) will assist with data on vegetation cover. The Flood Management cluster as a whole will therefore integrate and collaborate with other research clusters of the NBCBN-RE.

During the first phase of the project, a literature review has been performed on flood forecasting systems in order to define the necessary components. The second phase will focus on how to implement these components in a flood and drought forecasting system that is applicable in various sub-catchments of the Nile Basin.

Summary

This report focuses on problems related to Flood Forecasting and Early Warning in the Nile Basin. There is an urgent need to apply meteorological and hydrological information in order to generate flood risk information. Flood risk information is not readily available for decision-making by relevant authorities. In order to develop and operate a flood forecasting and warning system, real time data collection is vital.

Sufficient human capacity and resources to understand flood forecasting and early warning for flood prone areas in the Nile Basin is of paramount importance, given the fact that floods are the single most destructive disaster that destroy property and life to foremost the poor people in the Basin. This can be developed and achieved by building and sharing knowledge and experiences within the Nile basin.

Hydrologic and hydraulic river flow models are used as components in actual flood forecasting schemes, where forecasts are required to issue warnings and to give lead time for the evacuation of populations threatened by rising water levels. The basis of such forecasts is invariably observations and/or predictions of rainfall in the upper catchment, and/or of river flows at upstream points on the Main River or tributaries. Forecasts of the discharge will be obtained in real-time by using models to transform the input functions into a corresponding discharge function of time.

There are currently two main approaches employed in hydrological forecasting.
The first is a mathematical modelling approach. In general, a rainfall-runoff model is used to transform point values of rainfall, evaporation and flow data into hydrograph predictions by considering the spatial variation of storage capacity. A hydraulic channel flow routing model is then used to calculate the flows. An example of this type of deterministic modelling is the River Flow Forecasting Model (RFFS), a large-scale operational system currently employed on the Outer River Catchment.
The second main approach to flood forecasting is modelling the statistical relationship between the hydrologic input and output without explicitly considering the physical process relationships that exist between them. Examples of stochastic models used in hydrology are the autoregressive moving average models (ARMA) and the Markov method.

In the first phase of this project a literature review has been performed on flood forecasting for the following subtopics:
- River gauging network layout;
- Rainfall-runoff model used for each identified network;
- Model identification and recommendation for pilot experiments and eventually adoption;
- Data base review, including rainfall and hydrological data;
- Data analyses;
- Survey and mobilization of available data and network for a selected research area, both related to rainfall and river flow;
- Identification of the data sources and required data;
- Review of existing applications of GIS and remote sensing in flood forecasting.

In the second phase, the research aims at developing a flood and drought forecasting and early warning system for flood and drought prone areas in the Nile basin countries. This will be done

by starting with the development of such a system in a pilot basin, which after extensive testing can also be extended to other sub-catchments in the Nile region.

1. Background

This research report is an outcome of the first regional Workshop on “Flood Management” held in Kenya from 22nd to 24th September 2003. The main goals of the workshop were to establish the Kenyan Node under the Nile Basin Capacity Building Network for River Engineering (NBCBN-RE), to set up a regional cluster in Flood Management and to identify research projects to be undertaken by the node. The Kenyan node has cluster members from Sudan, Egypt, Ethiopia, Kenya, Tanzania, Uganda and Rwanda.

The workshop has also identified two specific research topics, which will be covered by two separate research groups namely,

- Flood and Catchment Management;
- Flood Forecasting and Early Warning.

The report at hand focuses on Flood Forecasting and Early Warning. The first phase of the project was covered in six months (November 2003 – April 2004). Basically the aspects, which necessitate capacity building and research in the field of Flood Forecasting and Early Warning in the Nile Basin are multiple and will be outlined in this chapter.

Flood problems leading to significant damage and casualties
In recent years there has been serious and widespread flooding within the Nile Basin, resulting in loss of life, damage to ecosystems, and risk to public health, and damage to property and business with significant economic implications. Furthermore the geographic and orographic characteristics of certain areas in the Nile Basin make them especially vulnerable to flooding. In addition to the direct costs of flooding in terms of damage to property and businesses and loss of life, it also creates a significant threat to the short and long term quality of water resources within the Nile basin.

The river Nile crosses several national boundaries and this makes it impossible for most riparian countries to monitor the potential onset of flooding in isolation. These flood problems also require an understanding of many complex interacting physical phenomena and can only be addressed by multidisciplinary teams working in close liaison. The flood management capacity building project of NBCBN-RE therefore enables researchers within the relevant disciplines to gain sufficient background knowledge to enable them to function effectively in flood management.

Increasing damage due to increased human settlements in the floodplains
Preliminary investigations have shown that human activities in the watershed, for example deforestation or irrigation, could bring about changes of flow in the river. Furthermore potential flood damages are increasing as a result of an increased human settlement in flood-prone areas.

Flood problems have been neglected so far and reactions, if any, have always been afterwards
The fact that flooding is an uncertain phenomenon raises issues about the reliability and credibility of flood forecasting and warning systems. It has been noticed that advance-warning, evacuation and flood control are effective and sustainable methods of reducing the devastation caused by floods. Despite the seriousness of this problem, not much attention has been given to the uncertainty of putting in place real-time flood forecasting systems. The existing disaster

management mechanism is primarily geared towards strengthening rescue and relief arrangements during and after major flood disasters rather than minimising the incidence and extent of flood damage. The number of times the sub-basins of Nile River have suffered destructive floods without any serious mitigation action is a clear indication of neglecting the importance of the problem.

Inadequate capacity to forecast floods in the Nile Basin

Capacities for flood risk monitoring and management in the Nile Basin are still weak. Flood risk information is not readily available for decision-making. There is an urgent need to apply meteorological and hydrological information in order to generate flood risk information. In order to develop, operate and undertake an early flood warning system real time data collection is vital in addition to measuring precipitation accurately. Tremendous capabilities are offered by radars in tracking the motion of severe thunderstorms, which can increase peak discharges when moving in the direction of the drainage area. However in the region there is no weather radar network, which can play this vital role. The number of both rainfall and flow monitoring stations are not adequate and the existing ones are in deplorable state due to poor maintenance. This leads to insufficient and unreliable data. At the same time data-transmitting capability of modern satellites has immense potential for hydrological applications especially in the area of flood forecasting. This needs to be exploited.

There is a potential to forecast floods

In view of the experts' pool available, there is a big 'human potential' to forecast floods in the Nile Basin. These opportunities have to be exploited with capacity building programmes and training on database and model development, data analysis and transmission, and operations in flood forecasting and early warning.

The impacts of Climate Change and increased Climate Variability

Climate change will call upon an urgent need for flood and drought forecasting and early warning tools. The magnitude and frequency of extreme events tend to vary with climate pattern. The future need for an integration of drought and flood forecasting and early warning is obvious. Besides, many structural and non-structural flood mitigation measures and strategies are also applicable for drought mitigation; hence, integration of strategies and policies will increase efficiency rates and benefits larger parts of society.

Catchment management practices

The sustainable development of adaptation strategies to cope with increased climate variability will rely heavily on flood/drought forecasting and early warning as well as (pro-active) catchment management practices (adaptive river management). Coping with present and future river (engineering) related problems on a basin scale would need the implementation of an International River Basin Organization.

2. Problem Definition and Analysis

2.1 Introduction - Floods as a Natural Disaster

“Flooding has occurred throughout recorded history and as a natural phenomenon has no regard for mankind and its activities” (Walsh and Brassington, 1990). Evidence of this is that while deaths from most natural disasters have declined over the past two decades; loss of life from flooding has increased (Grentfest and Huber, 1989).
The flood is at the present time only in fifth place as an agent responsible for loss of life. It has, however, the fastest growth rate in terms of frequency and number of human lives affected (Watanabe, 1988).

Floods only become a hazard when they affect human activities adversely and often go unrecorded or even unnoticed if they occur in uninhabited areas (Ward, 1978). However, it is generally assumed that floods are one of the most serious natural disasters and can cause much more damage than a tropical cyclone or earthquake.

As the risk of flooding is a severe hazard to human life, activities and structures, there is need for prevention and protection policies, which aim at reducing the vulnerability of people and property. Though the solution for flood mitigation and prevention seems simple, it involves a vast amount of data and knowledge about the causes and influencing factors of floods and their resulting damage.

The improvements in technology, particularly in the hydrological and meteorological fields, have increased the availability of facilities for the accurate collection, storage and processing of data. These data can be channelled into forecasting systems and warning networks to provide optimum protection to man, structures, communication networks and agricultural activities so as to minimize the loss of life and property. An accurate prediction and prior warning can greatly reduce the damage costs and loss of life due to a flood disaster.

As the world population is ever increasing, the critical demand for living space is becoming more apparent. This demand has led to the encroachment and development of high-risk areas such as floodplains. The inhabitants of these floodplains often disregard the risk of flooding, either due to a genuine ignorance of the danger or a false sense of security provided by structural designs constructed to ‘control’ floods.
The degree of personal protection adopted by inhabitants in flood risk areas is usually proportional to the level of their flood experience. A person who has experienced many floods will often be well prepared. However, such experiences are naturally associated with fear, which causes panic and delayed evacuations in emergency situations. A reluctance to abandon possessions can further increase the delays and risk to life.

Flood Forecasting and Early Warning
One of the main problems in flood forecasting and early warning is to determine how much warning is enough. Using a system that has an effective warning rate of say 70% may cause a reduction in flood related losses of 40%, whereas a 90% effective system may only reduce losses by 43%. Determination of the level of warning necessary and the effectiveness of such a system depends mainly on the amount of capital available for the development of an appropriate system. This is disturbing since the level of warning should depend on how many lives are at risk, potential property loss and other physical catchment variables.

The more affluent societies will incur great losses in terms of financial costs, but have the security of well-organized emergency services and insurance. As a result of such services and technology these societies will usually also benefit from an accurate warning system. In underdeveloped countries, like in the Nile Basin, human loss will far outweigh monetary costs. The cheaper, high-risk land on the floodplains is often densely populated - floodplains being attractive areas for development because of their close proximity to water supplies and relatively flat topography. Emergency services and warning systems are in most instances non-existent and people living in these regions have to rely on *'word-of-mouth'* warnings. The lead-time offered by these warnings is rarely adequate to allow a timely evacuation.

Due to scientific and technological advances in recent decades, the researchers' capability to predict flood events in affected Nile Basins will be greatly enhanced and improved. Dissemination of warnings based on these predictions will also be improved. The weather forecasting prediction capacity is fairly developed although the application methods of meteorological information are still at development stage. Capacity building efforts are required to advance warning on weather related disasters, especially floods and droughts.

2.2 Specific Problems in the Nile Basin Countries

Definition and causes of floods

Floods are unusually high rates of discharge and/or water levels, often leading to inundation of land adjacent to rivers and streams. They are mainly a result of quick-flow rather than base-flow, and are usually caused by intense or prolonged rainfall, snowmelt or a combination of these factors. Other causes are increased rainfall intensity or duration, reduced infiltration capacity and increased runoff due to deforestation, or a change in the efficiency of drainage networks.

No suitable forecasts of rainfall available

Weather forecasts have traditionally been issued with the agricultural community in mind. The qualitative forecasts issued are to some extent useful to the agricultural community but rarely to experts in water resources management. In flood forecasting, it is important that the weather forecast is interpreted to derive the amount of rainfall and consequently the runoff expected from a catchment. Most hydrological models require quantitative forecasts as input. There is need for meteorological experts to be encouraged to provide weather forecasts downscaled to suite the water resources management experts. This implies a more intensified cooperation and collaboration between institutes and agencies responsible for on the one hand weather forecasting and on the other hand flood forecasting.

Suitable network layout for relevant observations on rainfall and river gauging

Flood monitoring and forecasting is most efficient when done in real-time or near real-time. The process requires meteorological and hydrological flow data on a real-time basis. Unfortunately the stage-measuring networks in most areas of the Nile Basin are not functioning on a real-time basis. For example in the Nzoia River Basin in Kenya, there are 3 real time meteorological observing stations, which require telecommunications networks to be useful in a flood forecasting system. However, there are many registered rainfall stations but the majority of these operational stations are not functioning real-time.

Appropriate rainfall-runoff- river flow models have to be selected and adopted for the local situation

Stream flow modelling is a key tool in water resources management, early warning for flood hazards and related impacts. Many and advanced types of models exist but they have been developed in diverse climate regions. Hence they need to be adapted to the local situation before applying them in the Nile Basin.

How to identify the relevant indicators, issue the early warning and take required measures

Increasing encroachment of floodplains and riverine areas by the people is one of the major causes of a steady rise in flood damages over the years. There is therefore an urgent need to formulate appropriate land-use policies and legislation for proper regulation and control of human activities in and around the floodplains and flood-prone areas. The model, which has to be developed, is expected to use rainfall estimates from the upper catchment, which will in turn generate aerial flood hazard maps by the use of GIS tools.

Defining criteria for the development of a flood forecasting and early warning system

The river basins, which have been selected for initial model development, are the Nzoia (as a pilot basin) and Nyando basins in Kenya, the Simiyu basin in Tanzania and a wadi in Sinai Egypt. Specific aspects to be considered in flood forecasting include the flood frequency and magnitude. An early warning system will be designed and the end users of this system will be the government organisation responsible for disaster management and evacuation in respective countries. Efforts should also be sought to link the activities with the Nile Basin Initiative, which plays a critical role in regional activities. The most important data needed for model simulation is hydrological and meteorological based, however the data currently available has missing gaps and real time operational observation stations are few if available. Depending on the kind of forecasting system that will be developed, also topographic, geographic and river geometry data have to be collected. Ways of improving data acquisition in the catchments should be evaluated in order to retrieve a reasonable amount of data for meaningful model calibration and simulations.

3. Objectives

The objectives of the research in the first project phase are derived from the following perspectives:

- **Overall:** develop sufficient human capacity to understand flood forecasting and early warning aspects for specific flood-prone areas in the Nile Basin;
- **Specific:**
  - Understand the generics of a flood forecasting and early warning system;
  - Evaluate the generic data requirements in relation to the available baseline information within the Nile River Basin;
  - Apply the identified weather models that are appropriate, according to criteria used in their identification, in specific flood prone areas (hot-spots) within some Nile Basin countries, e.g. Nzoia River and Nyando River in Kenya, Simiyu in Tanzania and Wadi in Sinai region in Egypt;
  - Build and share knowledge, experiences and information in flood forecasting and early warning within the Nile Basin;
  - Develop a network of flood management experts within the Nile Basin;

4. State-of-the-art in Flood Forecasting and Early Warning

4.1 Introduction

Flood forecasting and prediction capabilities evolved slowly during the 1970s and 1980s. More recent advances also have a major impact on forecasting methodologies. Hydrological models forecast flood conditions based on predicted or measured parameters, through physical detection systems, or a combination of the two approaches.

River flow models are used as components in actual flood forecasting schemes, where forecasts are required to issue warnings and to permit the evacuation of populations threatened by rising water levels. The basis of such forecasts is invariably observations and/or predictions of rainfall in the upper catchment, and/or river flows at upstream points on the main river or tributaries. Forecasts of the discharge are obtained in real-time by using the model to transform the input functions into a corresponding discharge function of time.

There are currently two main approaches employed in hydrological forecasting. The first is a mathematical modelling approach. It is based on modelling the physical dynamics between the principal interacting components of the hydrological system. In general, a rainfall-runoff model is used to transform point values of rainfall, evaporation and flow data into hydrograph predictions by considering the spatial variation of storage capacity. A hydraulic channel flow routing model is then used to calculate the flows. An example of this type of deterministic modelling is the River Flow Forecasting Model (RFFS), a large-scale operational system currently employed on the Outer River Catchment (Moore et al., 1994).
The second main approach to flood forecasting is modelling the statistical relationship between the hydrologic input and output without explicitly considering the physical process relationships that exist between them. Examples of stochastic models used in hydrology are the autoregressive moving average models (ARMA) of Box & Jenkins (1976) and the Markov method (Yakowitz, 1985).

Models that provide a physically sound description of the hydrological processes occurring in a basin would have significant advantages over purely empirical models. The main advantage is, its accuracy and the possibility to perform solid sensitivity analysis. Their parameters have a direct physical interpretation, and their values might be established by field or laboratory investigations.

Flood Early Warning Systems (FEWS) are used for predicting water levels and discharges at specific locations along a river network. Based on these predictions the authorities involved may decide to implement flood mitigation measures or to evacuate people and livestock. Hence, it is important that accurate predictions for a time-horizon as long as possible are made. Delft Hydraulics has developed several Flood Early Warning Systems (FEWS). Examples are the Nile FEWS in Sudan (Elzein & Adam, 1996) and the Indus FEWS in Pakistan. The computational backbone of a FEWS usually comprises an ensemble of mathematical models, viz. a rainfall-runoff model (if applicable, including snowmelt), reservoir routing models and a hydrodynamic (i.e. SOBEK) routing model. In order to make flood forecasts, it is essential that the computed hydraulic and hydrologic conditions (de Roo & Schmuck, 2003) meet the actual observations. In order to achieve this, FEWS is regularly updated using available measurements. In the hydrodynamic (SOBEK) part of FEWS, Delft Hydraulics applies Kalman Filtering (KF), a data assimilation technique in which the optimal actual hydraulic condition of the hydrodynamic (SOBEK) model is established by statistically weighing computed and observed water levels and discharges.

4.2 United States Experience

Flood forecasting systems that have been developed by the American National Weather Service (NWS) include:

- The NEXRAD Doppler radar;
- The Advanced Weather Interactive Processing System;
- The Automated Surface Observing System;
- HEC-2 hydraulic modelling system.

The ***United States Geological Survey (USGS)*** uses up-to-date stage-discharge rating curves and river-stage readings (NWS, 1994) to estimate accurate river discharges. An important characteristic of a stage-discharge rating curve is that the process also works in reverse; given a discharge estimate, the corresponding river stage can be determined. This functionality enables the National Weather Service (NWS) to transform an obscure river parameter, its discharge, into an easily visualized and well-understood measure of public risk, the flood stage.

Flood Forecasting
River flood forecasts are prepared by 13 NWS river forecast centres in close cooperation with USGS, and disseminated by NWS offices to the public. During periods of flooding, the NWS river forecast centres issue forecasts for the height of the flood crest, the date and time when the river is expected to overflow its banks and the date and time when the flow in the river is expected to recede within its banks. These forecasts are updated as new information is acquired.

River Flood Warning
To develop flood forecasts, the NWS develops and calibrates complex mathematical models of how the nation’s rivers and streams respond to rainfall and snowmelt. These models are developed (NWS, 1994) for pre-selected forecast service points, which are usually located along major rivers or on small streams near urban areas that have a history of flooding. In every case, records of river discharges must be available, on the basis of which the NWS can develop a river model. An important hydraulic input to these models is the USGS stage-discharge rating curve. The resulting model is rarely exact, but it provides estimates of river response to rainfall. Thereafter, when heavy rainfall is forecasted for the river basin, those amounts are entered into the model, and the model estimates the foreseen river stage and discharge. As new river and rainfall data are collected during a storm, the new data are entered into the computer, and new river forecasts are produced.

During the preparations of forecasts flows into large rivers from upstream points and tributary streams must be considered. In fact, gauging important tributary streams is often needed even at locations where forecast services are not provided. These points are used in the forecast models as verification or control points. Because none of the models can predict exactly what will happen on a river, the use of river stages and the associated rating curve to reassess continuously how much water is in every stream is a vital part of the forecast process. Even a well-calibrated model is an ephemeral commodity. Once a river model is developed, changes in watershed characteristics, such as increasing urbanization, drainage improvements, and construction of dams and levees, can make the model obsolete. A continuing cycle of model calibration, collection of river-discharge and rainfall data, and model recalibration is required to provide a current, useful, and accurate flood-forecasting tool.

The City of Austin (Texas) uses a Flood Early Warning System (FEWS) designed to monitor rainfall, creek flow, and water levels, 24 hours a day, 365 days a year. Components of the FEWS include:

- Approximately 40 creek and lake gauges that monitor water levels;
- Approximately 80 rain gauges that monitor rainfall rate and amount;
- Real-time gauge data transmission to the Emergency Operations Centre (EOC);
- Automated data transfer every 15 minutes to the National Weather Service;
- Advice to the Office of Emergency Management (OEM) about current and expected flooding.

An integrated response with the Austin-Travis County EOC is in place such that, if signs indicate potential or active flooding, the Office of Emergency Management (OEM) is immediately notified so they can effectively coordinate emergency response and release flood information to the community and media. In emergencies, many agencies work closely together in the EOC to rectify the situation in the quickest and safest manner.

Approximately 7,000 houses and over 300 bridges in Austin are subject to flooding. Even with this early warning technology and coordination, every rainstorm is different and can cause sudden and unpredictable flooding effects. Flash flooding and localized flooding can sometimes occur faster than citizens can be warned or emergency personnel can respond. This is why every family, especially in flood prone areas, needs to take personal responsibility to prepare in advance for flooding.

The prediction system involves NEXRAD, the next generation radar, which is 10 times more accurate than any existing radar. It includes software that can translate rainfall into actual accumulation for a very specific region every six minutes, something researchers have not been able to do before. This, combined with geographic information systems (GIS) that display actual landscape images from satellite and historical knowledge of flooding in the area, will provide a complete, highly accurate system for predicting floods and flood severity.

4.3 European Experience

On the short term, floods cannot be totally prevented (de Roo & Schmuck, 2003). Recent large river floods, like the one in the Elbe and the Danube in 2002, have shown, however, that emergency, civil and water management agencies benefit from an increase in lead-time to efficiently implement their plans in downstream areas to reduce the flood peak. This could enable them for example to more effectively evacuate people from high-risk areas, or to release water from upstream reservoirs in a controlled way, creating temporary retention basins to reduce flood volumes and peaks. It could also help the European Commission (EC) and international aid organizations to better prepare and coordinate their actions.

European Flood Alert System (EFAS)

The EC are currently developing a prototype of a European Flood Alert System (EFAS). The advantages of EFAS for the EC and other international organizations are that it:

- Gives an overview of the actual flood situation in Europe;
- Gives a potential early warning for upcoming floods up to 10 days in advance;

- Gives comparable results across Europe;
- Allows a harmonization of hydrological data and data exchange in Europe.

The advantages for national authorities could be:
- Providing additional early warning information for National Weather Agencies (NWA);
- Creation of backup intervention and emergency services;
- Catchment based forecasts, giving downstream countries an overview of the upstream situation;
- Helping in interpretation of forecasts from different weather services;
- To compute scenarios with so-called Ensemble Prediction Systems (EPS) in order to quantify uncertainties of forecasts.

The work on EFAS commenced at the beginning of 2003 with the building up of the data infrastructure and the set-up of the model on a European scale. At present the system runs in a qualitative mode twice a day using forecasting data from the German Weather Service (DWD). The spatial resolution of the system is 5 km. A high-resolution quantitative database for meteorological and hydrological data is being constructed. The priority catchments at present are the Elbe and the Danube river catchments. EFAS is based on the application of the LISFLOOD model, developed in the floods group of the Weather Driven Natural Hazards action of the Institute for Environment and Sustainability (IES). LISFLOOD is a spatially distributed (WRSRL, 2003) water balance model that forms the backbone for more detailed modelling practices in different regions within Europe or for individual (trans-national) basins. It has been adapted to run for all the basins in Europe with a horizontal resolution of 1-5 km. The objectives of the EFAS are:
- To increase the lead-time for reliable flood warnings from a maximum of 3 days at present to 4-10 days and beyond in the future;
- To design a medium-range flood forecasting system for the whole of Europe;
- Produce flood forecasts in regions where at present no forecasts are made on the basis of the newly developed system;
- Give a measure of the uncertainty of the flood forecast.

Modelling Systems in the UK (RAINSIM and MTB)
The Water Resource Systems Research Laboratory (WRSRL) of the University of Newcastle has made substantial progress in the development and application of stochastic point process and rainfall field models (O'Connell, 2003). Two rainfall modelling systems have evolved from this work: (i) a rainfall time series analysis and simulation package (RAINSIM), which is suitable for hydrological studies requiring long generated time series at one or more sites, and (ii) a stochastic space-time rainfall field modelling system (MTB) which can be used for the simulation and forecasting of frontal rainstorms.

RAINSIM is a user-friendly modelling system designed to meet the needs of both researchers and practicing hydrologists. The system can be used to analyse existing records, to fit a single site or multi-site time series model to the data, and to simulate data at a specified number of sites and for any required sampling interval. At the heart of RAINSIM is a clustered point process spatial-temporal model in which the parameters relate to underlying physical features that have been observed in rainfall fields e.g. convective and stratiform rainfall features. The model structure incorporates multiple types of rain cells, which can be used to represent convective and/or stratiform rainfall. The model also enables multi-site (i.e. spatially consistent) rainfall to be simulated over a catchment. A flexible model fitting procedure is adopted which allows the selection and fitting of a desirable set of rainfall statistics for a particular application. As part of the UK Pollution Management Research Programme executed by the Water Research Centre at Swindon, the parameters of the single site clustered point process model in RAINSIM have been regionalized across the UK. This allows rainfall inputs to storm sewer system models to be simulated at any location in the UK. The model has been validated by comparing observed and generated extreme values at several sites. RAINSIM is fully compatible with Microsoft Windows.

The Modified Turning Bands (MTB) modelling system has been designed to simulate or forecast the spatial and temporal distribution of rainfall in frontal storms. The main structural features of frontal rainfall (rain cell cluster potential regions and rain bands) are represented by the MTB system.
The forecasting mode of the MTB modelling system has been implemented with an interactive front end on a UNIX workstation, allowing the operator to employ subjective judgment during storm forecasting. The system is written in C++, giving high computational and graphical display efficiency.

4.4 African Experience

The extent of flooding in Kenya
In the month of May 2003, thousands of people were reportedly displaced in Busia, Kisumu and Baringo districts in Kenya, and roads rendered impassable in parts of both these districts. Over 30 people were feared dead across the country. Nairobi experienced severe water shortages following bursting of the Sasumua water reservoir due to current heavy rains. Torrential rains affected Busia, Nyando, Kisumu, Karachuonyo and Migori districts. The overall rainfall in flooded locations, were well above the long-term average and the corresponding period in the previous year.

The impacts of these floods were extensive, causing both loss of human life and destruction of property (see plate 1 and 2). Serious damage to the road infrastructure, breaking out of waterborne diseases and food shortages followed in the affected areas. According to the early warning unit of the Kenyan Ministry of Agriculture, over 20,000 people were rendered homeless and over 10,000 hectares of crops were destroyed.

Plate 1: Flood victims forced to evacuate in Western Kenya

Plate 2: Flood damage in Western Kenya

Flood Risk Monitoring Project

Following major flooding caused by 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 activities 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 (Mileti, 1999*)* for a pilot basin in Kenya (the Nzoia River) that flows into Lake Victoria. Spatially distributed input to the model includes the US National Oceanic and Atmospheric Administration (NOAA; Climate Prediction Center) estimates of daily rainfall totals, USGS- developed global land cover and 1-kilometer digital elevation model, derivative datasets developed for hydrologic applications (HYDRO1K), and FAO soil layer at 1:1,000,000 scale. The results from the 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 stream flow and inundation 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.

Flood Early Warning System (FEWS) in Sudan

The Khartoum plains, the floodplains of Atbara and the main Nile were severely flooded during August-September 1988. Because of this, a Flood Early Warning System (FEWS) was installed in the Nile Waters Directorate of the Ministry of Irrigation and Waters Resources in Khartoum (Elzein & Adam, 1996), based on the main river gauging stations on the Blue Nile and Atbara river system. The FEWS model is used to enable more advanced warning for future floods from the Nile. The FEWS model consists of three main components:

1. A Primary Data User Station (PDUS) with relevant software for receiving and processing of METEOSAT thermal infrared images on a half-hourly basis (AUTOSAT\ARCS). These data are used to estimate daily rainfall quantities from cold cloud duration and the coverage data over the catchments of the Blue Nile and Atbara River.
2. A communication system for real-time transmission of water levels in the Blue Nile, Atbara River, and the Main Nile in Sudan to the Flood Warning Centre in Khartoum (MOIWR);
3. A computerized flood forecasting system, consisting of a set of mathematical models (SAMFIL\NETFL), and a temporary database embedded in an appropriate user interface.

Forecasting Procedure FEWS Sudan

Flood forecasts are carried out with the following set of models:

- Daily Rainfall Estimation Models
  In the absence of real-time information about rainfall over the Ethiopian Plateau, TAMSAT Group at the University of Reading (UK) developed a method (model) for real-time rainfall estimation. The presence of cold clouds with temperatures lower than a predetermined threshold is used as an indication of rain. The total rainfall within a certain period is associated with the cold cloud duration (CCD) and the portion of the catchment area covered or cold cloud cover (CCC).
- Rainfall- Runoff Model
  SAMFIL is an upgraded version of the well-known Sacremento model, extended with a Kalman filter data assimilation algorithm. The model is used for the real-time forecasting of the inflow from the Blue Nile and Atbara catchments into the main Nile in Sudan.
- Rainfall Forecasting Model
  In order to increase the lead-time, rain forecasts are statistically derived from rainfall records. Wet, average and dry scenarios have been derived for the months July, August and September from the CCD for the year's 1987-1990 using rainfall frequency curves. For the remaining months, a scenario was derived from the monthly data of the nearby point rainfall statistics.
- Flow Routing Model
  The Water and Environmental Dynamics (WENDY) model, extended with a Kalman filter, is used for real-time forecasting of water levels and flows in the Blue Nile, Atbara River and the main Nile down to Dongola. The model is a one-dimensional flow model based on the numerical solution of the St. Venant equations, using the finite difference method.
- Flood forecasting
  Forecasts are made for a period of ten days. This is approximately the lead-time between rainfall events over Ethiopia and the rise of water level at Dongola in the Main Nile. The lead-time for Khartoum is approximately six days. By using remote sensing data and rainfall runoff models, three additional days are gained for flood forecasting for the Ethiopian catchments of the Blue Nile and Atbara River at the Sudanese Border.

Sudan FEWS is in operation since August 1992, providing an advanced operational tool that gives a lead-time of three days ahead at El Deim, using remote sensing data and hydrologic modelling techniques.

The results achieved so far are promising, although further studies are required to improve the system efficiency.

4.5 Asian Experience

Flood Forecasting in New Zealand

Meteorologists and hydrologists of the National Institute of Water and Atmospheric Research (NIWA) can now forecast floods, which are caused by heavy rain, with greater lead-times, thanks to new research results (Gray, 2003). NIWA, in collaboration with Regional Councils, is now implementing this research as an operational forecasting technique. Each day, flood forecasts will be made for river catchments throughout New Zealand, using linked computer models of the atmosphere and river catchments. The forecasts will look 36 hours or more into the future. These will be broadcasted in summary form on the NIWA's website and through other media channels. The NIWA forecasts will be broadcasted in terms of their predicted severity: moderate (smaller than the 5-year flood), severe (once every 5 to 20 years), extreme (bigger than the 20-year flood). Detailed forecasts will be distributed to Regional Councils who supply their river flow data to NIWA for use in the forecasting process. This river flow data is needed to ensure that the forecasts are as accurate as possible, and to produce regular reports on the accuracy of forecasts. These new forecasts from NIWA will not alter the Regional Councils' role as the primary source of public flood forecasts. They have local knowledge that allows forecasts to be combined with on-the-ground knowledge of flooding, and translated into emergency responses by local organisations such as Police, Civil Defence, District and City Councils.

Indus flood early warning system: Pakistan

The Flood Forecasting Model (FFM), a composite set of rainfall-runoff models and river flow routing models, is the backbone for predicting water levels and discharges at key locations within the River Indus Basin. The rainfall runoff models are based on the WL|DelftHydraulics SAMO model, while the river flow routing models are based on the WL|DelftHydraulics SOBEK model.

FFM incorporates flood control measures such as flood mitigation by using the storage capacity of Mangla reservoir and diversion of floodwater near important bridges and barrages. In times of floods, the predicted hydraulic conditions in the FFM are regularly updated by assimilating on-line collected rainfall, water level and discharge data.

Data assimilation is required for creating a better hydraulic starting condition for the prediction of future flood conditions. The applied data assimilation method is based on the Extended Kalman Filtering Technique.

Flood Study in the Meghna - Dhonagoda Polder: Bangladesh

Bangladesh, situated in one of the world's highest precipitation areas, is accustomed to flooding due to its low topography with some of the world's biggest rivers flowing through it, and occurrence of cyclones. GIS and remote sensing provide tools for determining areas affected by floods or for forecasting areas likely to be flooded due to high river discharges.
A flood study was performed in an area (35 km^2), which is part of a polder that lies in the middle of the Meghna floodplain that occupies a small area at the confluence of the Ganges and Meghna River. The area has an elevation of 0.9 m to 3.66 m a.m.s.l. Spatial data stored in the digital database of the GIS, such as a digital elevation model (DEM), can be used to predict the spatial effects of future flood events. The extent of inundation and the depth of flooding can be forecasted.

The GIS database may also contain agricultural, socio-economic, communication, population and infrastructure data. This can be used, in conjunction with the flooding data, for the development of evacuation strategies, rehabilitation planning and/or damage assessment.

5. Research Results First Project Phase

5.1 Introduction

In this chapter a number of models, which could be used to develop a flood and drought forecasting system, are briefly described. The data requirement of the various models is discussed in summary in view of establishing a database in the second phase of the project. Criteria for selection of flood forecasting models as well as drought forecasting models are shown in Table 5.2.

5.2 Model Identification for Flood Forecasting and Early Warning Systems

The following models were reviewed out of several others and presented during the 2nd workshop in Nairobi (May 2004):

i. MIKE 11 Hydrodynamic model plus GIS;
ii. CARIMA model;
iii. Finite Element Surface-Water Modelling System (FESWMS);
iv. USGS/FEWS NET Geo-spatial Flow Model (GeoSFM);
v. Galway Flow Forecasting System (GFFS);
vi. High resolution Regional Model (HRM);
vii. Regional Spectral Model (RSM).

These models are briefly described below.

MIKE 11 Hydrodynamic model plus GIS

This model was developed by Danish Hydraulic Institute and is a widely applied dynamic modelling tool for rivers and channels. It produces real-time forecasts of river flows and water levels. The model comprises of three main modules namely; the Rainfall Runoff (RR) module, the Hydrodynamic (HD) module and the Flood Forecasting (FF) module. MIKE 11 has a Geographic Information System (GIS) component,, which has tools for describing, analysing, modelling and integrating forecasted flood levels with other related information such as topographic, thematic and attribute information. The model offers new opportunities to develop and implement a user-friendly, interactive decision support system for flood forecasting and identifying the affected areas using dynamic spatial modelling.

Flood warning systems and expert knowledge are integrated in emergency response strategies, to produce GIS flood prone area maps and detailed flood risk maps. These maps are required to minimize the harmful effects of flood hazards. The model produces flood forecasts and information for warnings in advance, i.e. 72hrs, 48hrs and 24hrs. Such forecasts can render informed decision making in adopting proper measures towards disaster preparedness, mitigation, control, planning and management. This kind of advance warning can help the authorities for better flood preparedness and also effective flood mitigation.

CARIMA model

CARIMA is a quasi-2D model, developed by SOGREAH, Grenoble (France). It is based on the 1D Saint-Venant equations, continuity equation and the momentum equation. The output data consist of discharge $Q(t)$ and water depth $H(t)$ at the computational points, water depth $H(t)$ in the floodplains and $Q(t)$ and/or $H(t)$ for the hydraulic links.

Finite Element Surface-Water Modelling System (FESWMS)
The FESWMS model was developed by the Scientific Software Group in the US. It is a 2*DH* hydrodynamic model code supporting both super and sub-critical flows. The flow is assumed to be strictly two dimensional except for special cases of weir and culvert flow. The model allows users to include weirs, culverts, drop inlets, and bridge piers in a standard 2D finite element model. Moreover, both steady state and transient solutions can be performed with FESWMS. It can be used to compute water surface elevations and flow velocities at nodes in a finite element mesh representing a body of water such as a river, harbour, or estuary.

USGS/FEWS NET Geo-spatial Flow model (GeoSFM)
The Geo-Spatial Flow model was developed by the United States Geological Survey (USGS). It is a Geographical Information System (GIS) based hydrological model and runs under ArcView environment. The hydrologic component of the Geo-Spatial Flow model system is physically based. The basic unit of this model is the basin, which is the subject of a daily water balance calculation. The model has an upland headwater basin routing module, and a major river channel routing module. Within basins, surface runoff is simulated using a source-to-sink method, while subsurface contributions to stream flow are modelled with two conceptual linear reservoirs. In the major river channels, water is routed using a non-linear Muskingum-Cunge scheme.

The model requires daily precipitation, evaporation potential, topography, soil information, land cover and land-use data as in put. Organizations that provide the necessary data are the United States National Oceanic and Atmospheric Administration (NOAA), USGS, the United Nations Food and Agriculture Organization (FAO) and the national meteorological and hydrological services.

The Geo-spatial Flow flood model uses the Hortonian overland flow, saturated overland flow and through flow to convert precipitation into runoff. The method developed by the US Soil Conservation Service (US-SCS) is used to estimate excess rainfall. The determination of the unit hydrograph in this method starts by estimating flow accumulation based on basin topography. Flow across a surface will always be in the steepest down slope direction. Once the direction of flow out of each cell is known, it is possible to determine which and how many cells flow into any given cell. This information is used to define watershed boundaries and stream networks. Using land cover in conjunction with soil information, a layer of the US-SCS runoff curve number (RCN) is build. The US-SCS RCN is used to partition rainfall incident on the basin into separate surface runoff and infiltration. The model uses the land-use, land cover and soil data to calculate response functions of each basin.

Preliminary tests on the model have been performed for the Nzoia River Basin (Figure 5.1) in western Kenya as shown in Figure 5.2. The Nzoia River covers an area of 12,000 km^2 and drains into Lake Victoria. The basin consists of the southern and eastern slopes of Mt. Elgon (4,209 m) and the western slopes of the Cherangani Hills, with the dominant topography consisting of rolling hills and lowlands in the Eldoret and Kitale plains. This basin is prone to frequent floods, which results in loss of lives and increases the level of poverty in the region.

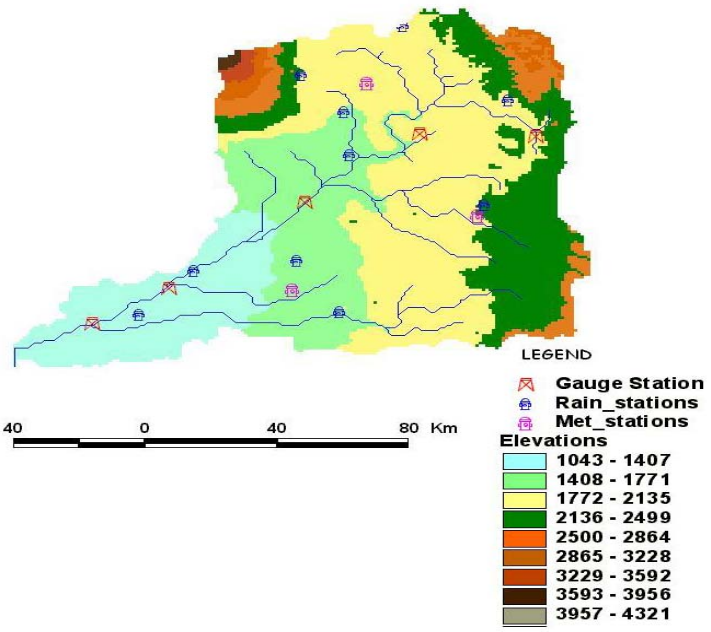

Figure 5.1 Nzoia River Basin

The model fits well compared to the observed flow as can be seen in Figure 5.2. However, the peak and low flows seem to be over and under estimated respectively. More research work is needed to find out how these high and low estimates can be reduced. High estimates could in some cases lead to a false warning. A correlation coefficient (r^2) of 0.88 was computed based on observed flows as compared to estimated flows. After this test run on the model it was found to be promising. The advantage of this model is the ease of availability of the necessary data to run the model. The model can also produce a flood prone area map, which is useful for planning and evacuations.

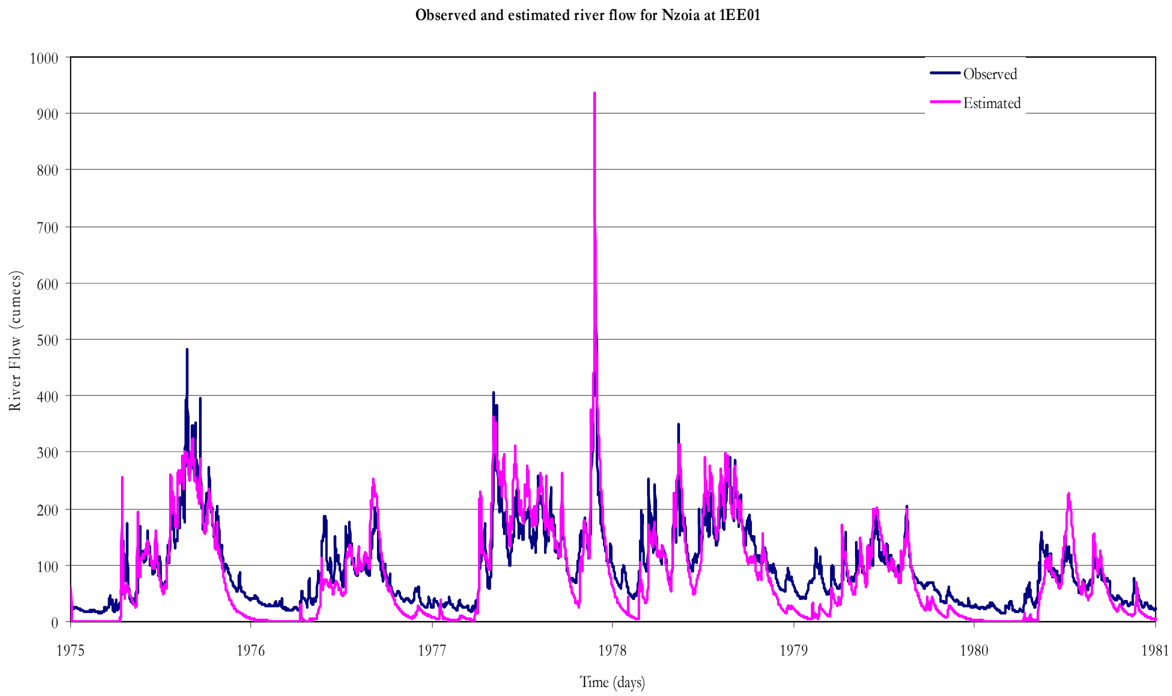

Figure 5.2 Model results of observed flow and estimated flows in Nzoia River Basin

Galway Flow Forecasting System (GFFS)
This software was developed by the Department of Engineering Hydrology, National University of Ireland, Galway, Ireland. This package includes a program for the computation of flow forecasts and provides information to issue relevant flood warnings.

GFFS uses 5 models, four of which are statistically based and one physically based model. These models are the Simple Linear Model (SLM), the Linear Perturbation Model (LPM), the Linearly-Varying Gain Factor Model (LVGFM), the Soil Moisture Accounting Routing (SMAR) Model and the Artificial Neural Network (ANN) model. The SLM is a linear regression model of the observed discharge vs. observed rainfall. The LPM exploits the seasonal information inherent in the observed rainfall and discharge data series. The LVGFM performs well in large catchments. For catchments characterized by strong seasonality, the LPM outperforms the LVGFM. For smaller catchments, the SMAR model performs consistently better than the LPM. The ANN model provides a flexible non-linear mapping of the network inputs into the network outputs without specifying a priori the mathematical nature of the relation between inputs and outputs.

GFFS software uses five performance evaluation criteria to evaluate results of the models namely, the coefficient of efficiency, R^2 (Nash & Sutcliffe, 1970), the Index of Agreement, IoA (Willmott, 1981), the coefficient of determination r^2, the Index of Volumetric Fit (IVF), and the Relative Error of the peak (RE).
The coefficient of efficiency (R^2) is defined by a dimensionless expression (Nash & Sutcliffe, 1970), given by:

$$R^2 = 1 - \frac{MSE}{F_o}$$

Here F_o is the initial variance of the data, expressed as:

$$F_o = \frac{1}{N}\sum_1^N \left[(Q_o)_i - \overline{Q}_c \right]^2$$

and the *MSE* is the Mean Square Error defined by:

$$MSE = \frac{1}{N}\sum_1^N \left[(Q_o)_i - (Q_e)_i \right]^2$$

$(Q_o)_i$ is the observed discharge and $(Q_e)_i$ is the estimated discharge at the i^{th} time step, N is the total number of data points in the discharge data series, and $\overline{Q}_c$ is the mean of the observed flow series during the period of calibration only.

The Index of Agreement, *IoA*, is defined (Willmott, 1981) by:

$$IoA = 1.0 - \frac{\sum_1^N \left[(Q_o)_i - (Q_e)_i \right]^2}{\sum_{i=1}^N \left(\left| (Q_o)_i - \overline{Q_c} \right| + \left| (Q_e)_i - \overline{Q_c} \right| \right)^2}$$

in which the term in the numerator of the fraction is N times the *MSE* and the term in the denominator of the fraction is called the potential error. The other symbols have the same meaning as given for the coefficient of efficiency.

The coefficient of determination (r^2) is given by:

$$r^2 = \left[\frac{\sum_1^N \left[(Q_o)_i - \overline{Q_o} \right] \left[(Q_o)_i - \overline{Q_e} \right]}{\left\{ \sum_{i=1}^N \left[(Q_o)_i - \overline{Q_o} \right] \right\}^{0.5} \left\{ \sum_{i=1}^N \left[(Q_e)_i - \overline{Q_e} \right] \right\}^{0.5}} \right]^2$$

where $\overline{Q}_o$ and $\overline{Q}_e$ are the mean of the observed and the estimated discharge data series over the period considered, and the other symbols have the same meanings as given above.

The Index of Volumetric Fit (*IVF)* is the ratio of the total volume of estimated discharge to that of the corresponding observed discharge and is given by:

$$IVF = \frac{\sum_1^n (Q_e)_i}{\sum_1^n (Q_o)_i}$$

The Relative Error of the peak (*RE*) is defined as $RE = \frac{\left| (Q_p)_e - (Q_p)_o \right|}{(Q_p)_o}$, where $(Q_p)_o$ and $(Q_p)_e$ are the observed and the estimated values of the peak flow respectively.

While the coefficient of efficiency is the measure of the relative improvement of the model under study over the performance of the *naïve model*, whose forecast for all times is the mean of the flows in calibration, the coefficient of determination describes the proportion of the total variance in the observed data that can be explained by the model. The Index of Agreement seeks to overcome the insensitivity of the correlation-based measures to differences in the observed and the model-simulated means and variances. Values of these three criteria range between 0 and 1, with a higher value indicating a better efficiency. For the *IVF*, the value of unity indicates a perfect volumetric match of the observed flows with the estimated flow in a certain period, indicating water balance, and for the Relative Error of the peak, the lower the relative error the better is the performance of the model.

The GFFS models were tested at the Sagana River in Kenya. The models were ranked according to the coefficient of efficiency R^2, which generally showed a consistent pattern when compared with the Index of Agreement IoA and the coefficient of determination r^2.

Model	**Sagana (2,365 sq. km), Kenya**					
	R^2	**IoA**	**r^2**	**IVF**	**RE**	**Rank**
Calibration						
SLM	0.6949	0.8939	0.7065	1.0633	0.311	5
LPM	0.7438	0.9216	0.7439	1.0053	0.2841	4
LVGFM	0.7559	0.9287	0.758	0.9685	0.0414	2
ANNM	0.7681	0.9306	0.7681	0.9964	0.1926	1
SMAR	0.7443	0.9266	0.7483	1.0001	0.0986	3
Verification						
SLM	0.7261	0.8941	0.7711	0.9077	0.6205	5
LPM	0.7584	0.9168	0.7738	0.8908	0.5882	4
LVGFM	0.8262	0.9474	0.8316	0.9088	0.4201	1
ANNM	0.8206	0.9435	0.8288	0.9245	0.5338	3
SMAR	0.8211	0.9482	0.8211	1.1203	0.4716	2

Table 5.1 Results of tested model on Sagana catchment Kenya

GFFS was also used in hydrological studies regarding the runoff generation process in the Rufiji River Basin in Tanzania. A flood flow scheme was designed using the observed data at five conspicuous locations on the catchment. The model results were used to produce flood forecasts and inundation maps. Each map showed the extent of inundation with a set of colour indices, having the associated flood warning number, and the corresponding flooded area in square kilometres. This model has been selected for further studies in the second phase.

High resolution Regional Model (HRM)

The High resolution Regional Model (HRM) is a flexible tool for Numerical Weather Prediction (NWP). The Deutscher Wetterdienst Dienst (DWD) in Germany provides this comprehensive package to meteorological services, universities, and research institutes worldwide. This is a numerically based rainfall forecasting model. It is currently in use at the Kenya Meteorological Department. The model can issue rainfall forecasts for a maximum of three days in advance. This model fits well in flood forecasting as the rainfall forecasts could be used as inputs in the flood forecasting models. An example of the result of a model simulation is shown in Figure 5.3.

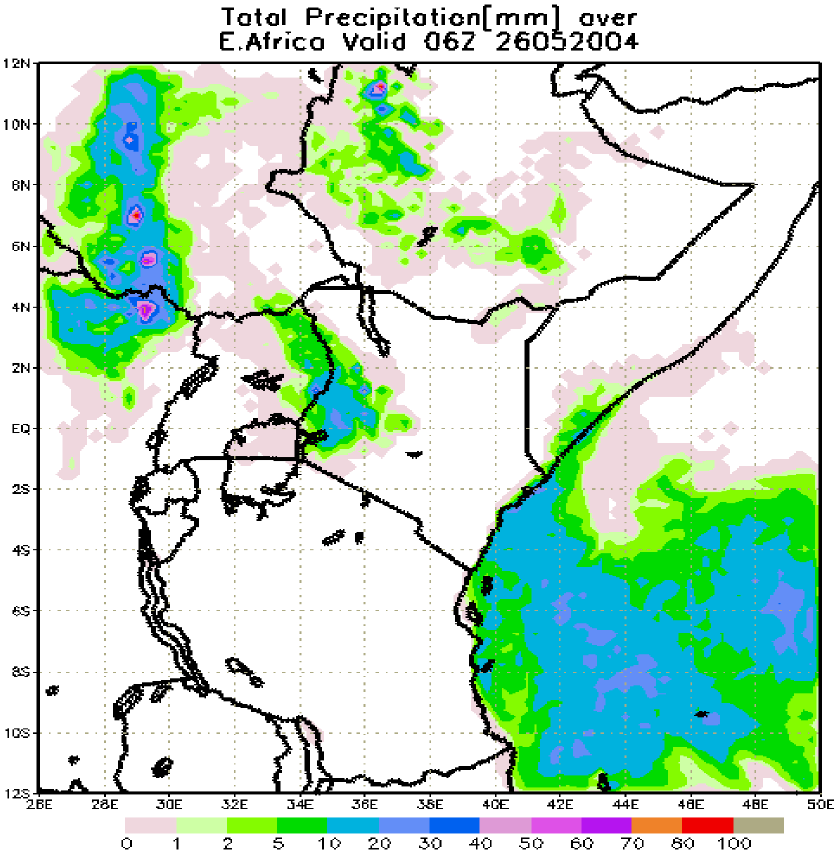

Figure 5.3 Rainfall forecasts by HRM of the Deutsche Wetter Dienst

Regional Spectral Model (RSM)

This model produces monthly and seasonal rainfall forecasts. It was developed by the National Centre for Environmental Prediction (NCEP) USA. This model is used by the IGAD Climate Prediction and Application Centre in Nairobi (Kenya), which is hosted by the Institute for Meteorological Training and Research (IMTR). In general, seasonal rainfall forecasts, which are routinely computed over the region, are sufficiently accurate to give an assessment of drought conditions. The model simulates detailed climate dynamics on monthly and seasonal scales.

Model Selection Criteria

After discussing the various models, criteria for the selection of models to be assessed in further detail in the second phase of the project have been defined. Table 5.2 gives a summary of these criteria. The models, which were selected for further evaluation, are the MIKE 11, GFFS, HRM and RSM.

Model	Data required	Availability	Expertise	Test Runs	Remarks
MIKE 11	Available	Not Locally available		Non	Capacity building required
CARIMA	Not Known			Non	Not well Known
FESWMS	Not Known			Non	Not well Known
GeoSFM	Local data Satellite data	Yes	Yes	Yes	Tested Locally in Kenya, Tanzania, Sudan
GFFS	Local Data	Yes	Yes	Yes	Tested Locally in Kenya, Tanzania
HRM	Available	Yes	Yes	Yes	Used in Kenya Meteorological department
RSM	Available	Yes	Yes	Yes	Tested Locally in DMC

Table 5.2 Model selection criteria

5.3 Data Base Review and Network Survey

The Nzoia River covers an area of 12,000 km^2 and is part of the bigger Lake Victoria drainage basin in Kenya, which forms part of the regional Nile river basin. The rainfall in the catchment ranges from 2,000 mm in the upper parts to less than 700 mm in the lower parts. The minimum discharge of Nzoia Basin is 28 m^3/s while the 100 yr flood is 930 m^3/s as measured in gauging station 1EE1. The flooding in the Nzoia Basin affects an area of 60 km^2 and a population of 24,000 people.

The main artery of the Nzoia River descends by 1,200 m over its 240 km length with slopes of approximately 0.5% in the upper reaches and reduces to 0.04% in the lower reaches where floods occur.

Meteorological data

A dense network of rainfall gauges and meteorological observation stations exist in the Nzoia basin of which three are real time meteorological stations. The real time meteorological stations are located in the middle and in the upper part of the catchment. The meteorological stations indicated in Table 5.3 have sufficient data available for model development of the Nzoia Basin.

Number	Name	Lat./Long.	Since	Remark
8934139	Nzoia River IRR	0°06'N 34°06' É	1969	Rainfall data
8934133	Mumias Sugar Project	0°21'N 34°30' E	1968	Rainfall data
8934138	Nzoia Forest Station	0°45' N 34°57' E	1968	Rainfall data
8934140	Turbo Forest Station	0°37' N 35°02' E	1969	Rainfall data
8935181	Eldoret EAMD	0°31' N 35°17' E	1972	Meteorological data
8935133	Eldoret Exp. Farm	0°34' N 35°18' E	1970	Rainfall data
8835024	Kitale	1°01' N 35°00' E	1950	Closed 1979
8835034	Cherangani	1o 03' 35o 19'	1956	Rainfall data
8934096	Kakamega Agromet	1o 17, 34o 46,	1957	Meteorological data
8834098	Kitale met	1o 00, 35o 59,	1950	Meteorological data
8934028	Kakamega forest	0o 14, 34o 52,	1935	Rainfall data
8934118	Sirisia chiefs camp	0o 45, 34o 30,	1962	Rainfall data
8834013	Chorlima ADC	1o 02, 34o 48,	1926	Rainfall data
8835039	Leissa farm kitale	1o 10, 35o 02,	1964	Rainfall data

Table 5.3 Selected Rainfall and Meteorological stations in the Nzoia Basin

River flow data

A total of 47 stream gauging stations, of which five are situated along the main Nzoia river artery, exist in the catchment. Stations 1EE1, 1BG7, 1BD2 and 1DA2 (Table 5.4) are stream gauging recorders of which 1EE1 and 1BD2 are equiped with data loggers. Also every major sub-catchment has a minimum of three stream gauges, especially in the upper reaches with high rainfall amounts. Table 5.4 gives a summary of the main stream gauging stations.

Gauge Number	Drainage (km^2)	Data since	Remarks
1EE1	11850	1962	Operational
1DD1	10142	1954	Operational
1DA2	8417	1947	Operational
1BD2	3825	1966	Operational
1BB1	1474	1948	Operational

Table 5.4 Stream gauging stations along the main artery of the Nzoia Basin

Network Survey

A number of organizations are currently working in the Kenyan side of Lake Victoria basin among which the Flood Forecasting and Early Warning research team should seek cooperation in the second phase of the project, namely:

- LBDA - Lake Basin Development Authority;
- LVEMP – Lake Victoria Environmental Management Programme;
- OSERIAN – Friends of Lake Victoria;
- WMO – World Meteorological Organisation;
- DMC - Drought Monitoring Centre, Nairobi;
- MOW – Ministry of Water Resources Management and Development;
- KMD – Kenya Meteorological Department.

5.4 Proposed Upgrading for Nzoia River

In addition, more measuring instruments on the Kenyan side of Lake Victoria Basin are planned to be implemented by e.g. the Kenya Agricultural Research Institute/Lake Victoria Environmental Management Project (LVEMP) who, with funds from GEF (UNDP), have invited bids for the supply, installation and commissioning of (Source: Daily Nation newspaper of 3/03/2004):

- 10 automatic weather stations;
- 20 automatic rainfall sensors;
- 110 staff gauges;
- 3 handheld laser range finder

Some of these instruments will be located on the Nzoia basin and in this way more Hydrometeorological data for model development will be available.

5.5 Assessment of Hydrological Data for Water Resources Development and Flood Control

Water resources development project may be broadly grouped into two categories, namely, water use and water control. Flood control falls under the latter category. In either case, however, the basic objective is to alter the natural distribution of water resources in time and space in such a manner that the project objectives are met within acceptable levels of risk. The quantification of risk is based on the availability of data. The ability to tackle water resources problems in Kenya and other developing countries is seriously constrained by scarcity of data.

A flood is any high flow that overtops either natural on artificial embankments along a stream (Chow, 1983). Flood control envisages the redistribution of flow both in time and space, which entails the design, and construction of flow control structures. These structures may be regulating (storage) or conveyance works in either case, the prediction of the flow hydrograph from a given rainfall is central in solving the problem of floods. Once a flow hydrograph has been determined, the flow can then be routed downstream.

In the study of hydrological processes, three types of uncertainty are recognized, namely, the inherent uncertainty in the process, model uncertainty and parameter uncertainty (Chow, 1983). These uncertainties complicate the task of developing reliable methods of flood prediction. Reliable methods can only be developed if sufficient data of good quality are available.

Problems with scarce data

In the Nzoia Basin, and other sub-basins of the Nile basin four types of scarcity or deficiency in data can be identified:

- Short records;
- Poor aerial coverage;
- Gaps in the data;
- Limited number of variables for which records are available.

The problem of short records

Rainfall, the principal natural process causative of floods is largely stochastic. The main danger posed by short data records is that they may not be representative of the long-term trend. The problem of short records is illustrated by Karthikeyan et al. (2003) who performed a frequency analysis of annual rainfall by using six common plotting – position formulae, namely, the california, Hazen, Weibull, Tukey Chegodayev and Blom methods. Observed annual rainfall for a 65 year period was available. This was divided into two sets; the first set was a subject data covering the first 20 years of record and the second was the complete 65 year data set. Equations were fitted for each set for the prediction of magnitude of annual rainfalls of various return periods ranging from 10 years up to 200 years. This is shown in Table 5.5.

Return period (years)	**Estimated annual rainfall (mm)**		**Difference**	
	Based on 20 years series	**Based on 65 years series**	**(mm)**	**Percent**
10	1542	1676	135	8.0
20	1743	1932	189	7.8
50	2009	2270	261	11.5
100	2210	2526	316	12.5
200	2412	2782	370	13.3

Table 5.5 Prediction of rainfall using a partial and complete series based on the Hazen formula (source: Karthikeyan et al., 2003)

For the area in question, Tamil Nadu in India, with a mean annual rainfall of 855 mm, the 8% and 13% difference translates, respectively to 135 mm and 370 mm of rainfall. Such quantities of precipitation are in the range of annual rainfalls for some regions of the world and even for the same area during drought years.

Problems of poor aerial coverage

The hydrometeorological stations in the Nzoia Basin are not evenly spatially distributed. There is a poor areal coverage of the hydro-meteorological stations. It is common that a catchment may have a hydro-met station at a remote point and data for a project may be available from some ‘nearby’ station. In areas of uniform relief, one representative station may be sufficient for expansive areas. In other cases, however, the data must be assessed and reworked to take into account such factors as altitude and relief.

6. Proposed Strategy Second Project Phase

6.1 Introduction

The rainfall patterns within Africa are determined by prevailing patterns of sea surface temperatures (SSTs), atmospheric winds, fluctuations of subtropical high pressure systems (Anticyclone) in the Indian and Atlantic Oceans, El Nino Southern Oscillations (ENSO), the Inter-Tropical Convergence Zone (ITCZ), tropical cyclones and local influence by mountains, forest and lakes.

Recent scientific reports issued by the United Nations, and more specific by the Intergovernmental Panel on Climate Change (IPCC), suggest that given the current projection of greenhouse gas (GHG) emissions, a 3º Celsius warming of global atmospheric temperatures is likely to occur by the later half of this century. It still remains unanswered how this global warming will affect rainfall patterns in Africa and the location of the climate and weather related hazards that they spawn.

It is estimated that on the global scale about 75% of the natural disasters are related to extreme weather and climate events such as floods, droughts, etc. In Africa, the vulnerability of the society to such events is much higher due to the poor economic status of most people, and this is true for the Nile Basin countries. Per capita, the Gross Domestic Product (GDP), life expectancy, infant mortality and adult literacy are all in the bottom quartile globally when averaged across Africa. Extreme climate events such as droughts and floods have far reaching impacts on economic activities in the Nile Basin countries. They often lead to loss of life and property, and the impacts are beyond coping capacity of many countries in the Nile Basin.

The 1997/98 El-Nino episode is the best recorded and studied weather related event ever and is sometimes called the 'El-Nino of the 20th Century'. Glantz (2001) used lessons learned from this event to identify problems in coping with impacts of El-Nino in Africa e.g.:

- Jurisdictional disputes among governments agencies due to a lack of clear policies on disasters;
- Forecast reliability;
- Lack of education and training;
- Lack of resources to cope with the situation in a preventive or mitigate way;
- Poor communication and;
- Poor weather observation and monitoring infrastructure.

Many of these aspects are not exclusive for coping with El-Nino events but apply to all manner of natural hazards like floods and droughts. Some of the proposed plans of action for the affected governments are:

- Better coordination between the various agencies concerned with the early warnings;
- Investment in monitoring networks and in strengthening of forecast capacity.

In this research, an attempt is being made to strengthen the flood and drought forecasting capacity as well as the early warning activities through the Nile Basin Initiative (NBI). Some of the components in a flood forecasting system and early warning that are necessary include:

- The technology to make quantitative forecasts (e.g. river flows and levels, rainfall amounts, etc.);

- A system to evaluate the forecasts and decide on a course of action (e.g. warning, evacuation, etc.);
- A system for implementing the actions (e.g. distribution and dissemination of the warning);
- A system for providing information or managing operations during the flood;
- A system for evaluating all the activities mentioned above after a flood.

In this research, emphasis is being put on how to strengthen flood and drought forecasting capacity and early warning activities. This will be achieved through collaboration and cooperation with relevant institutions and organization within the Nile Basin countries. For example, the Regional Institutes for Meteorological Training and Research (IMTR) will play a crucial role in generating quantitative inputs of the products from the Limited Area Models (LAM) currently being tested at the Kenya Meteorological Department (KMD). The Ministry of Water Resources Management and Development will be useful by providing the need for hydrological data, while the International Centre for Research on Agro Forestry (ICRAF) will assist with data on vegetation cover. The Flood Management cluster as a whole will therefore integrate and collaborate with other research clusters of the NBCBN-RE.

6.2 Objectives Second Project Phase

6.2.1 Scope

Floods are among the most damaging natural disasters that frequently affect many parts of the Nile Basin. Flood devastation ranges from loss of human lives to widespread destruction of crops, damage to houses and public utilities and disruption of various economic activities. Though flood protection works have been implemented, mostly in form of dykes are built from time to time, still the Basin is affected by floods.

The changes of flood intensity due to climate variability and change cannot be overlooked. There is need to monitor, using modern methods of collecting climate and weather data, and study of their impacts on river flow. River Flow Forecasting therefore needs to be introduced and integrated with the existing rainfall warning system to develop flood and drought forecasting and early warning systems. This calls for a strengthening of institutional linkages between Water Resource Management Institutions and the National Meteorological Services, community participation and National Disaster Centres. The region also suffers droughts quite often. It is therefore imperative that institutions that monitor drought are brought on board in this research activity e.g. Drought Monitoring Centre, Nairobi (DMC).

It is through this linkage that the provision and maintenance of systems for collection, and quality control of the observational data and their processing for the provision of real-time weather, climate and related environmental services will be possible.

6.2.2 Problem definition and analysis

Flood plains offer enormous advantages. The deep fertile alluvial soil is ideal for high crop yield, livestock farming and other economic activities. It is not entirely coincidental that Gross Domestic Product (GPD) per square kilometre for countries, which have well managed floodplains, is as high as in e.g. the Netherlands. The strategy for flood management in the Nile Basin therefore must simultaneously address the present problems of the poor floodplain dwellers and future development of the entire fertile land that is prone to frequent flooding. It is a fact that every main rain season (i.e. March, April, May and June), somewhere in the Nile Basin, the River Nile tributaries burst their banks and displace floodplain dwellers downstream and disrupt economic activities. In order to maximize net benefits from floodplains, multilateral cooperation will be required between Government, development partners and the Private Sector.

Drought is a normal feature of climate, and during this and the past century, the Nile basin has had numerous major droughts. Various droughts of different duration (long and short) have produced significant impacts in the Nile Basin countries. Severe droughts are accompanied by very serious socio-economic and environmental consequences. Impacts of both short-term and long-term droughts are aggravated by poorly conceived or nonexistent assessment and response efforts by various institutions and governments. In the past decade, considerable concern has been expressed within the scientific and policy communities about the inability of governments to respond to drought in an effective and timely manner. This has resulted in *call for action* by national and international organizations for improved drought management.

The research aims at developing a flood and drought forecasting and early warning system for the flood and drought prone areas of the Nile basin countries. This will be done by starting with the development of such a system in a pilot basin, which after extensive testing, can be extended to other basins in the Nile region.

The pilot basin is the Nzoia river basin in Kenya. The Nzoia river basin covers an area of 12,000 km^2 and drains into Lake Victoria. The basin consists of the southern and eastern slopes of Mt. Elgon (4,209 m a.m.s.l) and Cherangani hills on the western slopes with a dominant topography consisting of rolling hills and lowlands prone to frequent floods and droughts.

Hydrometeorological network for forecasting
A reliable hydrometeorological network is the key requirement for flood forecasting, particularly precipitation and stream flow data. In most cases the operational performance of the data network is the weakest link within the early warning system. Operational data must be examined.

Network design
It is not possible to manage water or forecast floods without data. Various types and sources of data are needed to monitor the environment, conduct a water balance or provide input to hydrological models that estimate stream flow from rainfall. Based on forecast needs, the adequacy of networks can be determined and required modifications can be noted. These could include new stream gauges, rain gauges and other telemetry equipment.

Data acquisition
Generally the design and operation of data networks have a large influence on forecast system accuracy and in the ability of the system to provide the necessary lead-time to issue warnings so that response actions can be taken. It should be underscored that the design of reliable real-time operational observing networks is critical to the success of a forecast, warning and response programme. In order to be effective during extreme conditions, sensor installations may have to be ‘hardened’ to withstand extremes in wind, rain or flood stage. The advent of remotely sensed data has significantly improved the ability of operational hydrology to infer watershed conditions in data-sparse regions. The application of radar-derived precipitation estimates serves as the principle tool in forecasting floods and flash floods in many countries. The use of geo-stationary and polar orbiting satellites to derive large volumes of

meteorological and hydrological products is rapidly advancing. Remotely sensed data can now be used to provide estimates of precipitation, vegetation type, land use, evapotranspiration, and soil moisture and flood inundation.

In the data review, pieces of data exist in some organisations and the task is in building a database to operationalise the forecasting system. The National Meteorological and Hydrological Services (NMHS) have real-time stations although not computerised. They are manually operated and efforts of data acquisition, using remote sensing like radar and satellite, are being strengthened within the NMHS's.

Data communication
For data to be useful to the forecast centre, point data observed at remote locations must be converted to digital formats. The format for the digital data must be specified. Remotely sensed images used in forecasts are usually provided in a specified digital format. Once data have been observed or collected at sites throughout the river basin or country, the data must be transmitted to locations where they can be stored, accessed, and used. The value of data increases with the speed of transmission and processing, from their initial observation to where they are used. Meteorological and hydrological data are needed almost instantaneously so that the hydrological forecast system can produce up-to-date and reliable forecasts. More importantly, this allows the system to provide the critical warning times needed for users to take actions. This is especially true for issuing warnings of flash flood events and of potentially hazardous mudslide conditions. There are many types of communication technologies that can be applied to transmit data from sites in remote locations to the forecast centres. The most common form of data communication is by telephone. However, telephone lines frequently fail during severe flood events. More reliable but potentially more expensive forms of data communications are satellite, line of site radio, cellular radio and meteor bursts. These also have their strengths and weaknesses. An evaluation should be performed to establish the most suitable, reliable and cost-effective form of communication for the local situation.

Network operation
Often the current operator of a site will not have had a need for, or experience with, real time data acquisition. Intensive staff training may be required to ensure that data are available when needed and are of a suitable quality. Long-term maintenance is a major requirement in operational forecasting. The forecast network may be in operation only seasonally or less frequently. Keeping the network in a state of readiness though necessitates major changes in operating philosophy. The development of water management operational forecasts by the forecast centre, as well as flood forecasts, enhances the usefulness of the data network and communications systems, as well as maintaining a state of readiness. Funding of alterations to existing networks and for future maintenance presents a major challenge. Negotiations between operating or funding agencies may require abandoning entrenched positions if success is to be achieved.

6.3 Activities and work plan

The proposed schedule for the second phase is shown in Table 6.1, assuming a two year project life.

Work plan (August 2004 – July 2006)

	Activity	Months					
		1 - 4	5 - 8	9 - 12	13 - 16	17 -20	21 - 24
1	Update information, literature and systems for both drought and floods						
2	Set up the data base for the sub basins						
3	First field workshop for Nzoia and Nyando basins						
4	First workshop for stakeholders at Simuyu basin.						
5	Adoption and testing of the model(s); field work as planned						
6	Initial development of capacity (training of researchers in GIS application)						
7	Identification of possible modes and media of issuing flood/drought forecast and warning;						
8	Second stake holders workshop						
9	Design of an Early Warning Protocol						
8	Report write-up						
9	Final Report						

Table 6.1 Second project phase time schedule and work plan

6.4 Expected outputs Second Project Phase

The expected output of the research will be:

a) Results on review of relevant available information, literature and systems currently in use world wide and within the Nile Basin countries. This exercise was completed in the first phase but in the second phase the emphasis will be on how to use the information to implement the recommendations already made based on the information. Moreover, a detailed analysis will be carried out in order to determine the integration of predicting drought events into flood forecasting and early warning.

b) Identification of a possible database within each participating county. The data will include amongst others rainfall and hydrological data. The review of the quality and accessibility of the data is very important. Establishment of collaboration links with organisations hosting the data will form an important part of the second phase.

c) An overview of models used in other countries and identification of appropriate model(s) for testing in Nile basin countries has been completed in the first phase. However, the actual calibration and verification of the selected model in the pilot basin will be very important in the second phase.
d) Identification of possible modes and media of issuing flood and drought forecasts and warnings for the selected study basins. There is an existing system of warning, which is not very elaborated and suitable for the modern flood forecasting system that is visualized. There is a need to review the system and improve it where shortcomings are identified. Furthermore, drought forecasting and warning should be linked to this system as well.

Establishment of a forum among researchers and professionals from Nile Basin countries in the area of flood forecasting and early warning is necessary in order to facilitate the exchange of information and dissemination of research outputs.

6.5 Expected inputs

Unlike the first phase, the project is to expand its scope to embrace both drought and flood activities. This will necessitate a firm support from the GIS & Modelling cluster of the NBCBN-RE. Integration is foreseen in the area of database and model development, development of flood hazard and inundation maps, flood risk assessment (incl. the dynamics of land-use patterns), catchment management and impact studies.

The implementation of sustainable river training structure(s) schemes in order to mitigate flood damages necessitates the cooperation with, and integration of River Structures cluster activities.
The environmental impacts and implications of flood (and drought) events, the effects of deteriorating catchments on those events and the development of sustainable coping and adaptation strategies have to be assessed in cooperation with the Environmental Aspects cluster. In this regard, cooperation with the River Morphology cluster will be needed to predict the effects of increasing soil erosion and sediment fluxes into channels and streams on (design) water levels and existing flood defence structures.
Cooperation with the Hydropower cluster will be needed to re-design reservoir operation schemes for multi-purpose use and to develop small-scale hydropower schemes for temporary retention of flood waters.

The following staff and time input are expected in the execution of the second phase. It is expected that all participating countries would make available any required research data, human resources and logistics when necessary. Table 6.2 shows the cluster member countries and their participation on the various activities of the research.

Activities	Cluster Member Countries				
	Kenya	Egypt	Tanzania	Sudan / Ethiopia	Uganda
Update information, literature and systems for both drought and floods	**X**	**X**	**X**	**X**	**X**
Set up the data base for the sub basins	**X**	**X**	**X**	**X**	X
First field workshop for Nzoia and Nyando basins	**X**	**X**	**X**	**X**	**X**
First workshop for stakeholders at simuyu basin.	**X**	**X**	**X**		
Adoption and testing of the model(s); field work as planned	**X**	**X**			
Initial development of capacity (training of researchers in GIS application)	**X**	**X**	**X**		
Identification of possible modes and media of issuing flood forecast and warning;	**X**	**X**	**X**		
Second stake holders workshop		**X**			
Design of an Early Warning Protocol	**X**	**X**			
Report write-up	**X**	**X**	**X**		
Final Report(compile)					

Table 6.2 Participation and cooperation with NBCBN-RE clusters during the second project phase

During the workshop and seminar on NBCBN-RE in Cairo, June 12 - 16 2004, the Flood Management cluster contributed with the following inputs, which are also applicable for the second phase of the project.

General

- A critical element in the contingency of the clusters and research groups, hence the NBCBN network, and the continuation and progress of activities is the facilitation and support of a minimal level of communication instruments and tools.
- The establishment of a knowledge and training centre for flood and drought management in East Africa is considered to be a long term solution for upgrading human capacity and resources, sustainable access to and standardisation of hydrologic, hydraulic & meteorological data and initiating research and development activities.
- The organisation of follow up workshops in ‘pilot catchments’, in which the participation of research group members, their higher management and, from data acquisition point of view, crucial regional flood and drought management institutes (ministries, agencies, etc.) is foreseen, could significantly contribute to the sustainable continuation of research activities, leading to tangible outputs beneficiary for the local communities and the NBCBN network as a whole.

- The possibilities for retrieving fellow and scholarships for capacity building, training and education should be improved. This is considered inside as well as outside the NBCBN network.
- The clusters and research groups will have to increase their own fund raising activities outside the NBCBN network. However, the NBCBN project management and scientific advisors should increase their support activities by assistance and guidance of proposal and tender development and informing individual clusters and research groups of cooperation possibilities and opportunities by linking up with other networks and programmes.

Integration

- The activities of the Flood Management cluster (both Flood Forecasting & Early Warning and Flood & Catchment Management) necessitate a firm support from the GIS & Modelling cluster. Integration is foreseen in the area of database and model development, development of flood hazard and inundation maps, flood risk assessment (incl. the dynamics of land-use patterns), catchment management and impact studies.
- The implementation of sustainable river training structure(s) schemes in order to mitigate flood damages necessitates the cooperation with, and integration of river structures cluster activities.
- The environmental impacts and implications of flood (and drought) events, the effects of deteriorating catchments on those events and the development of sustainable coping and adaptation strategies have to be assessed in cooperation with the Environmental Aspects cluster. In this regard cooperation with the River Morphology cluster is needed to predict the effects of increasing soil erosion and sediment fluxes into channels and streams on (design) water levels and existing flood defence structures.
- Cooperation with the Hydropower cluster is needed to re-design reservoir operation schemes for multi-purpose use and to develop small-scale hydropower schemes for temporary retention of flood waters.

Crosscutting issues

- The current scenarios on the impacts of Climate Change and increased Climate Variability will call upon an urgent need for flood forecasting and early warning tools.
- Increasing climate variability will lead to an increase (of the magnitude and frequency) of extreme events. The future need for an integration of drought and flood forecasting and early warning is obvious. Besides, many structural and non-structural flood mitigation measures and strategies are also applicable for drought mitigation; hence integration of strategies and policies will increase efficiency rates and benefits larger parts of society.
- The sustainable development of adaptation strategies to cope with increased climate variability will rely heavily on flood (& drought) forecasting and early warning as well as (pro-active) catchment management practices (adaptive river management).
- Coping with present and future river (engineering) related problems on a basin scale will need the implementation of an International River Basin Organisation.

7. Conclusions and Recommendations

7.1 Conclusions

On the basis of the first project phase, the Flood Forecasting and Early Warning research group concludes the following:

- Flood and drought forecasting is feasible and can minimize the suffering of the Nile Basin flood and drought prone dwellers, if stakeholders can and are willing to collaborate and mobilize their resources towards implementing the recommendations mentioned below;
- There is an urgent need to develop a reliable and robust data collecting infrastructure that is appropriate for a well functioning flood and drought forecasting and early warning system in the sub-catchments of the Nile Basin;
- Developing long-term solutions for capacity building, research, knowledge dissemination by upgrading existing training centres in East Africa to a level of centres of excellence in flood and drought management will contribute to reduce the vulnerability of particularly the poor to these extreme climatological events in the Nile Basin region;
- Intensification of cooperation and collaboration between the various research clusters of the NBCBN-RE is necessary in order to fulfil the objectives of the capacity building and research goals.

7.2 Recommendations

The results of the first phase of the project enforce the need for an in-depth look at the drought and flood problems in the Nile Basin countries. The strategy of the second project phase of the Flood Forecasting and Early Warning research team will mainly focus on:

- The development of a flood and drought forecasting and early warning system for the Nzoia Basin in Kenya. Therefore the team has to:
  - Establish databases to develop the system and to retrieve (on-line) operational information;
  - Actively encourage the implementation of real-time data stations in cooperation with on-going projects in the regions;
- Select and adapt simple to use and acceptable forecasting model(s);
- Simulate test runs, based on past flood and drought events;
- Prepare protocols for issuing early warnings (in close cooperation with relevant disaster management institutions)
- Organise workshops and field studies on site to exchange and disseminate information and research results as well as strengthening the cooperation between individual team members and members of the various NBCBN-RE research clusters.

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Ethiopia:
- Mr. Deksios Tarekegn (Head of the Department of Hydrology in the Ministry of Water Resources)

Uganda:
- Mr. Twinomujuni Jackson (Senior Hydrologist in the Ministry of Water, Lands and Environment)

Tanzania:
- Mr. Joseph Aliba (Tanzania Meteorological Agency)

Egypt:
- Dr. Mohamed Roushdy (HRI)

Sudan:
- *Name to be provided later*