Final Report

Design of an Upgraded Data Acquisition, Communication and Flood Forecasting Systems in the EN countries

submitted to

ENTRO

EASTERN NILE TECHNICAL REGIONAL OFFICE

by

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1. Introduction

Riverside Technology, inc. (Riverside) has been contracted by the Eastern Nile Technical Regional Office (ENTRO) to develop a procurement plan and terms of reference for Design of an Upgraded Data Acquisition, Communication and Flood Forecasting Systems in the EN countries. To report the results of this project, Riverside has prepared this Final Report.

The purpose of the Report is to: (i) describe the background and context of the project, (ii) present the results of the gap analysis, (iii) present an overview of the individual components that can be used for a real-time data collection network, (iv) provide recommendations for real time data collection networks in Ethiopia and Sudan, and (v) present a design for a data processing and storage and a data communication system.

2. Project Background

Historically, the flow of the Blue Nile and its tributaries that flow into Lake Tana reaches maximum volume in the rainy season (from June to September), when it supplies two thirds of the water of the Nile proper. Flooding along the tributaries to Lake Tana is not uncommon, and such flooding has beneficial effects for farming activities because of the sedimentation of fertile silts in the floodplains during these flood events. Severe flooding along populated areas, however, can also have devastating effects on lives, livelihoods, and property. Infrastructure, agricultural land, and other resources at risk from floods can be vast, and include residential, commercial and industrial property, and public service infrastructure, including water supply and crops. The Eastern Nile region is particularly vulnerable to these frequent and damaging floods, causing significant loss of life and economic damages.

Flood events originating in the Blue Nile River and its tributaries are of concern to the three Nile riparian countries of Ethiopia, Egypt, and Sudan. Flood events along the Nile are typically caused by heavy rainfall in the Ethiopian highlands. Flood flows then concentrate in Ethiopia and Sudan before traveling downstream into Egypt. Each of the three countries is interested in being able to forecast river conditions, but the unique characteristics of the river regime in each country yield a different focus for each country with respect to forecasting needs:

In ***Ethiopia***, ***localized, flash floods*** along Nile tributaries are of greatest concern. Example flood prone areas are Lake Tana and the Gambella plains. The Blue Nile River gorge is well entrenched, so that high flows in the gorge are generally not a safety concern. With the development of hydropower, however, there may be increased interest in hydrologic forecasting for reservoir operations.

In ***Sudan,*** the main ***riverine flood*** risk areas are located along the Blue Nile, the Main Nile, and the Atbara River. In addition, ***localized and flash flooding*** affects areas along tributaries to the Blue Nile, such as the Dinder and Rahad Rivers. The effects of these flash floods can be more severe when they coincide with flood flows on the Blue Nile.

High flows in the Nile River in ***Egypt*** affect mostly the ***operations of High Aswan Dam*** (HAD), which must be operated to prevent flood damage downstream while also preserving volume from year to year for hydropower, downstream agricultural production, and water supply.

2.1 The Nile Basin Initiative

The Nile Basin Initiative (NBI) is a partnership of the riparian states of the Nile: Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda**.** The NBI seeks to develop the river in a cooperative manner, share substantial socio-economic benefits, and promote regional peace and security. The NBI launched with a participatory dialogue process among the riparian that resulted in a shared vision: "to achieve sustainable socioeconomic development through the equitable utilization of, and benefit from, the common Nile basin water resources." The discourse also gave birth to a strategic action program to translate its vision into concrete activities and projects.

2.2 NBI's Strategic Action Program

The NBI's Strategic Action Program is made up of two complementary components: the basin-wide Shared Vision Program, to build confidence and capacity across the basin; and subsidiary action programs, to initiate concrete investment and action on the ground at sub-basin levels. The programs are reinforcing in nature. The Shared Vision Program lays the foundation for unlocking the development potential of the Nile by building regional institutions, capacity, and trust. This can be realized through the investment-oriented subsidiary action programs, currently under preparation in the Eastern Nile and the Nile Equatorial Lakes regions.

2.3 Eastern Nile Subsidiary Action Program (ENSAP)

The Eastern Nile region includes the countries of Egypt, Sudan and Ethiopia and encompasses the sub-basins of the Baro-Akobo-Sobat, the Blue Nile, the Tekezé-Setit-Atbara, portions of the White Nile in Sudan, and the Nile proper. The Eastern Nile countries are pursuing cooperative development at the sub-basin level through the investment-oriented Eastern Nile Subsidiary Action Program (ENSAP).

ENSAP seeks to realize the NBI shared vision for the Eastern Nile region, and is aimed at poverty reduction, economic growth, and the environmental degradation reversal throughout the region. Towards this end, the Eastern Nile countries have identified their first joint project, the Integrated Development of the Eastern Nile (IDEN). IDEN consists of a series of sub-projects addressing issues related to flood preparedness and early warning; power development and interconnection; irrigation and drainage; watershed management; multi-purpose water resources development; and modeling in the Eastern Nile.

IDEN projects are divided into fast-track projects and multi-purpose track projects. The fast-track projects consist of Flood Preparedness and Early Warning (FPEW), Eastern Nile Power Transmission Project, Eastern Nile Planning Model, Eastern Nile Irrigation and Drainage Project and Watershed Management whereas the multi-purpose track projects include the Eastern Nile Power Trade, Baro-Akobo-Sobat Multipurpose project and the Joint Multipurpose Project (JMP).

The Eastern Nile Technical Regional Office (ENTRO) is a technical regional body supporting the implementation of ENSAP. Established in 2002 and located in Addis Ababa, Ethiopia, ENTRO is responsible for providing administrative, financial management, and logistical support in the implementation and management of ENSAP. In general, ENTRO's core functions are: ENSAP coordination and integration; project preparation; financial management; communications and outreach; training; monitoring and evaluation; information exchange; and serving as the secretariat for ENSAP organizations.

2.4 Flood Preparedness and Early Warning Project

The FPEW fast-track sub-project is among the seven projects identified within IDEN. The objective of the FPEW project is to reduce human suffering caused by frequent flooding while preserving the environmental benefits of floods. The project gives emphasis to flood risk management and non-structural approaches to managing the impacts of flood. The FPEW project enhances regional collaboration and improves national capacity in the mitigation, forecasting, warning, emergency preparedness, and response to floods in the Eastern Nile basin.

The project was conceived to have four components, namely, flood mitigation planning, flood forecasting and warning, emergency response and preparedness, and regional component. The project preparation has an inception phase, project definition phase and finalization of documents after consultation with the key stakeholders. The inception included consultations, work plan and inception report. The project definition step included analyses, consultations, developing strategy, Technical Background Paper (TBP), draft Project Implementation Plan (PIP) and draft Terms of Reference (TOR). The finalization step involved revision, finalization of the PIP and TOR documents and debriefing. As a result, the Technical background paper reported the findings on the issues related to assessment of the flood risk in the sub-basin to support the flood plain management, recommendations on improved flood plain management in urban centers and rural communities, operational flood forecasting in the countries and mechanisms for exchange of information and data, improved emergency response by governments at all level and community preparedness, and enhancement of regional cooperation during flood events.

The technical background paper deliberated on the regional background; institutional aspects; climate of the countries and flood problems in the member countries; institutional context; social context; availability of flood related data; flood forecasting; flood warning, emergency response, post-flood relief and recovery; flood mitigation planning; environmental assessment; and regional activities. Moreover, the TBP outlined the program of activities in each country. The program of activity included more than 35 project elements. The project elements include the need for a network of reporting river and rain gages for both Ethiopia and Sudan that can meet the needs for both national and regional flood forecasting. This consultancy is focused on the need for a real-time data collection, data management, and data communications system to support hydrologic forecasting and flood early warning in the Eastern Nile countries.

2.5 Project Location

The project study area includes the Main Nile from Khartoum to the High Aswan Dam, the Atbara River, the Blue Nile in both Sudan and Ethiopia and all of its tributaries, and the Baro-Akobo-Sobat system. Major impacted areas include:

1. The Fogera , Dembia and Gambella plains (Ethiopia)
2. The Abbay River (Ethiopia)
3. The Tekeze River near Humera (Ethiopia)
4. The Blue Nile, Dinder, and Rahad Rivers (Sudan)
5. The Atbara River near Kubur (Sudan)
6. The White Nile near Malakal (Sudan)
7. The White Nile near Khartoum (Sudan)
8. The Main Nile between Khartoum and Atbara (Sudan)
9. The Main Nile near Dongola (Sudan)
10. The High Aswan Dam (Egypt)

The project location is shown in ***Figure 2-1***.

Figure 2-1: Project Location (shaded in red)

2.6 Existing Forecast Capabilities

Each of the three countries has instituted individual flood forecast efforts to mitigate flood damages to local populations and infrastructure. The differences in the types of floods encountered (as described above) motivate distinct approaches and methods with respect to flood forecasting in each country. This is reflected in the operations of the respective National Forecast Centers (NFC) and National Meteorological Agencies (NMA):

In ***Ethiopia***, the unique flood forecasting challenge is that to accurately predict and respond to localized flooding requires a dense network of automated rainfall and streamflow stations. Even then, lead times will be short, requiring a highly efficient system for hydrologic forecast development and for the dissemination of flood warnings. Real-time flood forecasting in Ethiopia is quite recent. Efforts to improve flood warning and preparedness under the FPEW I project include flood risk mapping within the Lake Tana basin and the implementation of Flood Preparedness Action Plans (Amhara). The HEC-RAS and HEC-MHS models used for the flood plain mapping were extended to a real time forecast mode for flood forecasting in the Fogera and Dembia flood plains. The extended HEC-HMS model uses the ETA model precipitation forecast. The models have been tested and made operational during the 2009 and 2010 flood seasons. However, a need has been identified for further testing and validation of these models.

In ***Sudan***, flood forecasting can utilize streamflow observations at stream gauges close to the Ethiopian border to forecast flooding along the Blue Nile and major tributaries. This can provide several days of lead time for the densely populated areas of Wad Medani, Hasahisa, and Khartoum downstream. Additional local flooding must be predicted based on rainfall and streamflow observations in Sudan and headwater areas in Ethiopia. Additional lead time for forecasting for the communities upstream of the Sennar Dam on the Blue Nile could be provided using forecast and observed precipitation in the Ethiopian highlands. A systematic arrangement for flood forecasting, warning and communication was established previously in Sudan, although some of the implemented forecast system components are no longer operational. Current efforts to improve flood forecasting under the FPEW I project include the hydraulic modeling using HEC-RAS and flood risk mapping for pilot areas upstream of Khartoum. Additional HEC models, as well as Linear System Type Models (LPM) are currently being integrated in the Deltares Sudan FEWS. The development of a flood forecast system for the Blue Nile includes hydrologic modeling of the Ethiopian highlands and a hydraulic model of the Blue Nile in Sudan, as well as the implementation of Flood Preparedness Action Plans in pilot flood affected areas.

Flood forecasting in ***Egypt*** relies to a very large degree on both flow observations at streams in Sudan and Uganda, on limited rainfall observations, and on satellite-based estimates of precipitation in the Ethiopian highlands. Extended probabilistic forecasts are developed based on ensembles of simulated runoff that combine historic precipitation traces with estimates of current soil moisture that are maintained by the hydrologic models. Using these data, the Nile Forecast Center provides regular flow forecasts in support of operations decisions for the High Aswan Dam. Current efforts under the FPEW I project focus on enhancing the operation of the existing Nile Forecast System (NFS). Detailed hydraulic modeling of the Blue Nile is of little benefit for Egypt, because decisions are based on the forecast information mostly related to inflows to the High Aswan Dam. Likewise, small incremental lead time that might be available from short term precipitation forecasts in Ethiopia is of limited value. Accurate estimates of daily precipitation, however, would be useful in improving satellite based precipitation estimates for rainfall runoff modeling, and observations of streamflow in Ethiopia would be helpful in improving the model estimates of soil moisture.

ENTRO intends to provide ***Regional Flood Coordination*** in Addis Ababa to support flood forecasting and mitigation efforts in Ethiopia, Egypt, and Sudan and to facilitate data exchange between the three countries. ENTRO's efforts will be designed to support the unique needs of forecasting in each country, and will endeavor to identify ways in which resources can be combined for benefits to all three countries.

3. Tasks

The terms of reference described specific tasks that were to be performed as part of the assignment. The following text notes each task and indicates where in the remainder of the report the information associated with that task may be found.

3.1 Task I – Review of existing flood forecasting systems in Egypt, Ethiopia and Sudan

3.1.1 Gap Analysis

The gap analysis is performed for each country individually, and compares the current status of the flood forecasting network with a desired outcome. The desired outcome is compiled based on a review of previously compiled documents, as well as feedback obtained from stakeholders on the inception report and the country visit performed in October 2010. The results of the gap analysis are documented in *Chapter 4 –Review of Existing Flood Forecasting Infrastructure*.

3.1.2 Forecast Point Definition

Forecast points are the location in the flood forecast system for which flood forecast warnings are issued during high flow events. The areas for which flood forecast warnings are desired is based on a review of previously compiled documents, as well as feedback obtained from stakeholders during the inception phase and the country visit performed in October 2010. Criteria for locating forecast points are discussed in *Chapter 4 –Review of Existing Flood Forecasting Infrastructure* and in *Chapter 5 -*

Network Design Considerations. Forecast points are coincident with hydrometric gage locations and specific recommendations gauge locations are documented in *Chapter 6 – Recommendations*.

3.1.3 Data Communication System Design

To improve flood warning in downstream countries along the Blue Nile and Main Nile, sharing of observed discharge and precipitation data in the upstream countries will be required. The communication of this data will be facilitated by ENTRO. The possible options available for the design of a data communication system are presented in *Chapter 5 - Network Design Considerations*, and recommendations for the system are provided in *Chapter 6 – Recommendations*

3.1.4 Flood Forecast System Recommendation

The focus of this study is on the design of a data collection network for flood forecasting. Desired outcomes for flood forecasting capability in each of the EN countries are included in the GAP analysis. *Chapter 6 – Recommendations* includes Riverside's recommendations for a general implementation strategy, institutional settings, data collection networks (including station types, station locations, sensors, and station infrastructure), telemetry, data processing and storage, and regional data sharing.

3.2 Task II – Define Operational Hydro-meteorological Network and Undertake Field Work

3.2.1 Remote Hydro-meteorological Observation Sites

The real-time data collection network will depend on reliable remote sites at strategic locations in order to automatically provide accurate information on the precipitation and river flows in the Eastern Nile Basin. Requirements for the location of the stations, as well as the equipment used at the remote stations are identified in *Chapter 5 - Network Design Considerations*. Recommendations for the sites, based on the considerations in *Chapter 5*, as well as the result of the gap analysis documented in *Chapter 4*, are documented in *Chapter 6 – Recommendations*.

3.2.2 Telemetry System

The observations at the remote stations need to be reported to the base station to be evaluated and processed. To provide near real-time information, an automated system is required to relay this information. Several systems area available that can be used to connect the remote stations to the base station. The available systems and their advantages and disadvantages are documented in *Chapter 5 - Network Design Considerations*, and the preferred telemetry system is reported in *Chapter 6 – Recommendations* based on the considerations in *Chapter 5* as well as the results of the gap analysis reported in *Chapter 4*.

3.2.3 Base Station

The base station will be the location where all the data collected at the remote stations will be received, analyzed, stored, processed and disseminated. A good location of the base station will allow for reliable operation of the station and quick dissemination of the flood forecast warnings. Requirements for the base station will be evaluated in *Chapter 5 - Network Design Considerations*, and recommendations are provided in *Chapter 6 – Recommendations*.

3.2.4 Field Work

At this stage of the design of a data collection system field work is necessary to establish a general understanding of the current status of hydrometric and meteorological stations and networks in each country and to make preliminary recommendations regarding the types of sensors that might be appropriate to measure water level at various river gauges. It was not possible to visit all of the gauge locations being contemplated for the proposed networks, but a sufficient number of gauges were visited in each country to provide guidance in the design of the networks. The field work is referenced in *Chapter 4 –Review of Existing Flood Forecasting Infrastructure*, and field reports for each country are included as ***Appendix A*** and ***Appendix B*** for Ethiopia and Sudan, respectively.

3.3 Task III – Review the Technical Back Stopping Capacity of RFCU

After the completion of phase I of the FPEWS (December 31st, 2010) which is associated with the closure of the Nile Basin Trust Fund (NBTF) in December 2012 the activities and functions of the RFCU were assigned to the WRPU of ENTRO. The capacity of the WRPU, as well as the steps that are required to allow the WRPU to be a hub for data dissemination among the countries and as technical support facility for the NFC's is evaluated in the gap analysis and reported in *Chapter 4 – Review of Existing Flood Forecasting Infrastructure*.

3.4 Task IV – Prepare Technical Specifications and Tender Documents

3.4.1 Procurement Plan

The Procurement plan provides detailed steps that each country will need to perform in order to implement the recommendations in this report. During the implementation of the steps outlined in the procurement plan, it is expected that lessons learned, as well as changed conditions, will require modifications from the original recommendations. The procurement plan contains mechanisms that will allow for the incorporation of lessons learned during the implementation of the system. The Procurement Plan is documented under a separate cover.

3.4.2 Technical specifications for procurement

In order for the real-time data collection system to operate satisfactory, the network will need to meet a minimum set of requirements. These requirements are summarized in the technical specifications document. Specifications are provided for all individual parts that make up the network, as well the minimum requirements for selected combinations of the individual parts of the network. The Technical Specifications for Procurement are provided under a separate cover within appendices to the Procurement Plan.

3.4.3 Tender Documents

Tender documents are required to procure equipment and installation services from vendors for the implementation of the system. Because there are multiple components and potentially multiple phases of implementation, separate tender documents are needed for each procurement. The Tender Documents provided under a separate cover within appendices to the Procurement Plan, together with the technical specifications.

4. Review of Existing Flood Forecasting Infrastructure

An important prerequisite in the design of a forecast data collection and communications system for EN countries is an assessment of existing infrastructure and capabilities to support hydrologic/flood forecasting. The assessment is performed in light of the desired outcomes associated with the design. This chapter presents a gap analysis, which is a three step analysis that first identifies a desired outcome, then describes the current status, and finally identifies the missing elements or gaps that need to be addressed to achieve the desired outcome.

The gap analysis is conducted separately for each country because each country has separate and distinct goals and because the achievement of the goals will be undertaken individually by each country. Because ENTRO will provide backstopping capability as well as a central data communications role, a separate analysis is presented for ENTRO as well. The desired outcome, current status, and gaps are described below in terms of forecasting capability, data collection network, telemetry, data processing and storage, regional data sharing, and the institutional support framework.

4.1 Ethiopia

As noted previously, the forecasting challenge in ***Ethiopia*** is to be able to accurately predict localized flooding in basins ranging from less than 500 km^2 up to 1,500 km^2, (Dirma, Megech, Rib, Gumara) as well as to predict flow volumes for larger rivers up to 175,000 km^2 (Tekeze, Baro-Akobo, Abbay). This requires more dense networks for the smaller sub-basins as well as a broadly distributed network of many stations for the larger river basins. Likewise, the response times from peak rainfall to peak runoff may range from several hours in the smaller basins to several days.

For the foreseeable future Ethiopia intends to centralize forecasting functions at a national forecast center (NFC) within the hydrology department of the MOWE in Addis Ababa. An important implication of this arrangement is that all data transmissions from the data collection network need to be directed to the forecast center for processing. This will be reflected in the desired outcomes described below.

4.1.1 Hydrologic Forecasting

4.1.1.1 Desired Outcome

Data inputs - the desired forecast capability will include the ability to accept and integrate the following inputs in real-time:

- Observed water level
- Observed discharge
- Observed point precipitation
- Gridded precipitation estimates (from radar or satellite)
- Forecast precipitation (usually a gridded input)
- Observed reservoir inflows, outflows, and pool elevations

Pre-processing – The system will need to be robust and flexible to permit forecasts to be developed even when some inputs are not available, especially those inputs where missing data are not uncommon or not essential, including missing station observations. Pre-processing functions may permit missing data to be estimated as necessary to perform hydrologic simulations.

Hydrologic simulation – a flexible framework for simulating hydrologic phenomenon, including rainfall-runoff, stream routing, and reservoir simulation is required. Because the rainfall –runoff response is non-linear and is dependent on initial conditions, a continuous model that accounts for variation in soil moisture based on antecedent precipitation observed in the system may be desirable. The system will need to be able to store and retrieve copies of model states for use in simulating with the continuous model.

Incorporation of observed streamflow – there will always be differences between observed and simulated streamflow. Where there is high confidence in streamflow observations, the system should be able to incorporate observed streamflow into the hydrologic simulation so that downstream routing algorithms are using the best available inputs. Reliable and frequently updated rating curves will be required to accurately determine the streamflow based on a water level observation.

Forecast points – the nature of most hydrologic forecast systems requires alignment between multiple factors associated with the locations of forecasts, including:

- Location of real-time observed streamflow, which is vital for verifying forecasts
- Subdivision of basins both to permit a forecast at a specific point, as well as to properly model the spatial variability of hydrologic response to rainfall

- Locations where forecasts are needed, such as at areas where flooding of population and infrastructure is likely or above water control structures that require forecasts for improved operation;
- Locations of water control infrastructure that both modifies and functions in response to upstream runoff hydrographs.

Forecast points are located to meet forecast needs and balance these considerations. For Ethiopia this will mean carefully selected forecast points as follows:

- Upstream of and within the flood prone locations around Lake Tana, as well as water level in Lake Tana (note that the outfalls of the tributaries into Lake Tana can be simulated in the hydraulic modeling approach, but are not convenient locations for discharge measurement);
- Upstream of and within the flood prone areas in Baro-Akobo basins;
- At key tributaries and along the Tekeze river, including at the Tekeze Dam site
- At key tributaries and along the Abbay river, with future sub-division as necessary to represent reservoirs that may be developed.

Automated execution – For small basins with very short lead times it can be important to be able to rapidly assimilate observed precipitation and generate a streamflow forecast to provide warning of extreme floods before they arrive. Automated execution of the forecast simulation in an unattended mode can provide a rapid notification of hydrologic conditions that need attention without waiting for a forecast operator to initiate the simulation. To be effective this capability needs to be coupled with the capacity for frequent ingest and simulation, on the order of once per hour. For large basins, the lead time may be sufficient to permit waiting for manually initiated simulation.

Forecast adjustments – For small basins with very short lead times, there is often no opportunity to fine-tune the streamflow forecast before a decision must be made to issue a warning. For larger basins however, it is beneficial to be able to take advantage of the available lead time to make adjustments to forecast simulations so that they better match observed streamflow. This can be done by increasing or decreasing the input precipitation pattern or adjusting initial conditions, for instance.

Hydraulic simulation – Where rivers open into wide flood plains, it can be difficult to estimate the extent of flooding and provide flood warning to populations at risk based solely on the estimated peak discharge. Hydraulic models may be required to permit a more precise estimate of river profile and extent of flooding, especially when coupled with the ability to define inundation extent based on real-time prediction of water levels. This would be of use in the Lake Tana floodplains as well as in the Baro-Akobo rivers.

Reservoir operations – For both small and large river basins with reservoirs, a reservoir simulation component will be helpful to be able to represent the effect of flood storage and release on the shape of the discharge hydrograph as it moves through reservoirs in the river system. This will become increasingly important as additional reservoirs are developed in coming years. The essential feature of the reservoir model is to be able to simulate reservoir storage, elevation, and outflow based on inflow and reservoir operating rules, allowing a forecaster to manually define outflows to override the operating rules as needed. The capability envisioned here is not intended to dictate the operation of the reservoirs, but to predict them.

Operational integration – The components that comprise the forecast system should operate together in an integrated fashion with an operational focus. This means that certain repetitive processes are automated, the components communicate with one another or with a central database so that manual intervention is kept to a minimum, and system is robust so that operations can proceed even in the absence of some of the expected data inputs.

Precipitation forecasts – Precipitation forecasts will be important for Ethiopia, especially for the smaller basins where there is little lead time between observed precipitation and arrival of runoff peaks at flood prone areas. The development of precipitation forecasts is usually the responsibility of a meteorological agency which produces the outputs in a form that can be ingested by the forecast system. This process will serve flood forecasting needs best if it is reliable and smoothly integrated with the hydrologic forecast system.

It has been suggested that the NFC should maintain a parallel version of numerical weather prediction models particularly for areas affected by flash floods to avoid delays and unforeseen circumstances of model failure in NMA.

Notification/dissemination – The forecast system capability typically extends to the development of products (graphics, tables, and text) that describe the forecasted conditions. A complete forecasting program will also include the subsequent protocols, procedures and associated tools necessary for notification to the responsible staff of critical conditions, and the dissemination of forecasts and warnings to the affected population.

4.1.1.2 Current Status

At present, hydrologic forecasting in Ethiopia is a recent development, with the first forecasts from a rainfall runoff model being produced for pilot areas around Lake Tana during the flood season of 2010. These forecasts were based on the models that were prepared as part of a Flood Risk Mapping consultancy in 2009 – 2010. The modeling framework consists of the following elements:

- Precipitation forecasts developed based on a regional ETA numerical weather prediction model;
- An event-based rainfall-runoff response simulation using the HEC-HMS hydrologic model; and
- Hydraulic routing simulation and flood mapping using the HEC-RAS hydraulic model and HEC-GeoRAS mapping application in ArcGIS.

These models were operated during the most recent flood season by Addis Ababa University staff and consultants at ENTRO, who also prepared the scripts and tools to automate some aspects of the interface between the individual models and their outputs and inputs. Results of the simulations were shared and discussed with staff at MOWE and subsequently distributed to officials in the pilot areas. Qualitative feedback from local officials to ENTRO suggests that the forecasts were both accurate and useful.

ENTRO also published weekly flood bulletins and seasonal forecasts which included longer term indicators of potential flooding conditions based on seasonal climatic factors. Daily precipitation forecasts using the ETA model were also produced by ENTRO during the flood season and the results were shared and communicated with the National Forecasting Centers.

4.1.1.3 Implications

The current forecasting capability in Ethiopia lacks the following elements:

- Observed data inputs (precipitation, water level, discharge, reservoir elevations)
- Spatial precipitation from satellite or radar
- Lack of adequate topographic data for Hydraulic Routing
- Pre-processing capabilities
- A clear understanding of hydrologic response of watersheds
- A continuous hydrologic model capable of managing model states
- Automated execution capability
- Flexible forecast adjustments
- Reservoir simulation component
- Operational integration
- Notification/dissemination

- Coverage for the majority of the eastern Nile basin

In essence, the pilot forecast system developed by ENTRO for the flood prone areas around Lake Tana links three models together to provide a rudimentary forecast capability where none existed before. It does not include the suite of advanced capabilities that are found in mature forecasting environments.

4.1.2 Data Collection Network

4.1.2.1 Desired outcome

The data collection network is described by the location of data collection stations, the specific parameters that are measured at each location, and the sampling interval, storage, and transmission capabilities of the station. For purposes of this analysis the data collection network includes the sensors, data loggers, battery and power supplies, but excludes the telemetry system which is discussed separately.

Precipitation – At the core of hydrologic forecasting is the potential to predict the runoff response of a basin to precipitation. It is the existence of a delay or lag between the occurrence of precipitation and the arrival of the resulting runoff that permits action in response to the expected runoff. Measurement of precipitation throughout a river basin is therefore fundamental to the development of forecasts.

To produce accurate forecasts, the precipitation network needs to be dense enough to represent the spatial variability of rainfall throughout the basin of interest. Small basins require a higher network density than large basins. Likewise, areas where runoff is dominated by convective storms require a higher network density than areas where major runoff is produced by synoptic rainfall. The predominance of synoptic rainfall during the flood season in Ethiopia suggests the need for a broad network of distributed precipitation stations upstream of the principal forecast points on the Abbay, Tekeze, and Baro-Akobo rivers and a higher density of stations for the Lake Tana sub-basins.

The precipitation stations should be able to sample rainfall data at hourly intervals and store the data for an extended period (several months) to permit manual data rescue at the station in the event that telecommunications equipment fails for any reason.

Hydrometric Network – observations of water level at locations with reliable discharge rating curves are essential for verifying the accuracy of forecasts in real time, as well as for subsequent calibration of models. Streamflow stations with water level sensors are generally located at all forecast points, where conditions permit. Conversely, forecast points may be limited to locations with active streamflow stations. The streamflow stations should be able to sample water level data at hourly intervals and store the data for an extended period (several months) to permit manual data rescue at the station in the event that telecommunications equipment fails for any reason.

Weather – Weather stations are needed to support the functioning of numerical weather prediction models that are used to provide precipitation forecasts. The station density will be less than the precipitation network, but greater than the synoptic network of data that are provided to the WMO. Station parameters include temperature, relative humidity, wind speed and direction, and solar radiation. These data need to be available to the NMA (or whoever will provide the precipitation forecast input to the system).

Station infrastructure – in addition to the parameters to be measured, each station needs to be robust and secure. Critical components include the following:

- Power supply – including solar panels, batteries, and cables designed to support power demands of all electronics based on expected available sunlight.
- Lightning protection, including lightning rods and grounding equipment
- Security – secure fencing, and locking hardware cabinets

- Mast – a tower on which to mount solar panels, sensors, and antennas for telemetry at appropriate heights
- Data logger with appropriate storage and programming capability to manage data transformations and transmissions.
- Telemetry (discussed below)

4.1.2.2 Current Status

A long term data collection network exists in Ethiopia, including a meteorological network operated by the NMA and a hydrometric network operated by the hydrology department of the MOWE.

Precipitation - The existing precipitation network is part of the climatic network of the NMA. Officials stated that there are more than 1000 stations in the network, although there are less than two hundred that report data to NMA headquarters on a daily basis. The remainder are climatic stations where observations are made manually on a daily basis by observers and reported monthly by mail through the local post office, or as frequently as NMA staff visit the site to collect the records. Some of the gauge equipment is fabricated by NMA.

Hydrometric Network – The hydrometric network is operated by the hydrology department. Stations are typically equipped with an automatic recording gauge to provide continuous measurements and with a staff gauges to permit manual observations for verification. Manual observers take water level measurements on a daily basis. Discharge measurement equipment is maintained at regional offices and discharge measurements are taken periodically, with the equipment and trained staff shared among many stations.

It has been reported that many of the stations are not adequately maintained and lack essential supplies. As a result, many stilling wells are clogged with sediment and do not provide accurate readings and automated recording equipment is not functional due to lack of paper and markers for recording fluctuations.

Weather Stations – The NMA in Ethiopia operates several classes of weather or climate stations among its network of over 1000 stations noted above under precipitation. The primary distinction between the classes is the number of meteorological parameters being measured. Class 1 stations measure all major parameters, class 3 stations only measure precipitation and temperature, and class 4 stations measure precipitation only. These stations provide daily reports. In addition there are a small number of synoptic weather stations (about 17) that provide reports on a 3-hour basis. These data are transmitted regularly to the WMO as part of its global observation network. Within the last year the NMA has installed a network of 20 automated weather stations that report by CDMA/GSM. These are not located in the Eastern Nile basin but in the eastern part of the country.

A field tour was conducted to visit representative sites, including many candidate sites for high priority implementation of automatic gauges. A field report is included as Appendix A. Important conclusions regarding the stations and the network are that the facilities and technology for streamflow and climate data measurement and observations are generally the same as what was implemented nearly 50 years ago. The equipment has deteriorated and has not been maintained in many cases, and spare parts and supplies are often no longer available because of the age of the equipment.

4.1.2.3 Implications

The data collection network is based on station equipment and sensors that are not compatible with automated data logging and telemetry systems. Therefore, any station that is selected as part of the real-time network will require upgrading of hardware and infrastructure, including sensors, data loggers, solar panels, batteries, cables, masts and any associated civil works.

4.1.3 Telemetry

4.1.3.1 Desired Outcome

The desired telemetry system is described separately from the data collection network because there are multiple options and associated tradeoffs that are mostly independent of decisions regarding the network layout and selection of sensors at various sites. The principal needs are as follows.

Reliability – the telemetry system needs to be available during critical conditions, when severe weather is occurring, when conventional means of communication may be stressed due to emergencies, or when power outages exist.

Reporting frequency – the telemetry system must be able to provide transmission of data at the reporting frequency required for the type of data, size of the basin, and forecasting requirements. Hourly transmissions should be acceptable for small basins, and three to six hour transmissions may be acceptable for larger basins.

Security – Ethiopia prefers a telemetry option that permits the control of all data and transmissions to be retained within the country. Sharing of data with ENTRO and other countries can be automated as part of the communications component but should be under the control of the Ministry.

Flexibility – it may be important for the telemetry system to allow flexible definition of transmissions, so that more frequent transmissions may be made from stations in the rapidly responding small basins and during seasons of heavy precipitation, with a reduced frequency during dry periods.

4.1.3.2 Current Status

The hydrometric station network operated by the hydrology department does not have telemetry associated with it. Regional staff travel to the stations periodically to collect the gauge records and then transmit them to the office in Addis Ababa.

The majority of the climate network operated by NMA has no telemetry and reports by mail. The manual stations that report daily do so by means of long wave radio transmissions to regional offices and NMA headquarters. Regional offices then report information to NMA by long wave radio transmissions or voice telephone.

A recent installation of about 20 automatic weather stations in the eastern part of the country report by CDMA/GSM. This network is accessible to NMA through a web page. It was not clear to NMA staff how the data transmission might be configured to permit automated transmission of this data to the hydrology department or automated ingest into NMA's numerical models. There also appear to be periodic lapses in data availability that are not yet completely resolved.

4.1.3.3 Implications

There is no functioning telemetry system in Ethiopia capable of providing real-time data to a hydrologic forecast system. What does exist is limited by timeliness of data (the radio reported data at NMA) or by lack of access, automation, and experience (the recently installed weather stations with GPRS coverage). A comprehensive telemetry system is therefore required.

4.1.4 Data processing and storage

4.1.4.1 Desired Outcome

When the observed data are transmitted to a central location, important processing functions take place. These functions are performed automatically and require that the receiving base station be available full time as a mission critical system. Failure of the system for even a short period of time can result in critical losses of information. This requires a robust power source with uninterruptible power supplies and backup power generators.

Precipitation data need to be processed to hourly accumulations at each station for use in the forecast system. Water level at river gauges should be processed through rating curves to yield estimates of hourly instantaneous discharge. A map display should be provided that permits a visual representation of the network with numerical and graphical depictions of recent observations of all parameter types. The data processing and forecast systems should permit close coupling to facilitate automated operation for small basins, as well as manual forecast execution for larger river basins.

The processing system should allow storing several months of observations, with tools for exporting the data to files or other systems for archival purposes. This permits the database to be optimized for real-time operations while permitting the data to be used subsequently for development of a historical climate and streamflow database.

The data processing workstation should be configured with a separate backup workstation with regular mirroring of data that can be quickly and easily configured to receive and process data.

4.1.4.2 Current Status

The hydrology department does not currently operate a real-time data processing system. Historical records are processed and archived in a database using the HYDATA program.

After receiving daily data reports from around the country, NMA staff enter these data into spreadsheets which are stored on a network. Staff who are responsible for running numerical weather prediction models at NMA access these data for input into their models. In some instances, if the data are not available in a timely manner in the spreadsheets, staff running the numerical models will manually copy information from the log books and transfer them to the models.

4.1.4.3 Implications

There is currently no real-time data processing capability for hydrometric data. The manual meteorological data processing capability at NMA is not compatible with real-time telemetry systems nor with the envisioned forecasting capability. A comprehensive data processing system is therefore required.

4.1.5 Regional data sharing

4.1.5.1 Desired outcome

Because Ethiopia is an upstream country, its direct needs for data sharing are limited, inasmuch as precipitation and streamflow data outside of Ethiopian territory have little or no impact on flood impacts within Ethiopia. There are, however, several elements of data sharing that may be of interest to Ethiopia. These are:

- Providing data to other EN countries as part of a general interest in outreach for reducing flood impacts in the EN region.
- Receiving meteorological data from other countries for numerical weather prediction models;
- Receiving Satellite precipitation estimation grids from the Nile Forecast Center in Egypt; and
- Providing precipitation data to Egypt to improve the satellite precipitation estimation grids.

It is assumed that data sharing would be organized by ENTRO, with each EN country providing data to ENTRO, which would then host a service from which each country download desired data. From this perspective, the important features of a data sharing system in Ethiopia are the ability to automatically retrieve weather data and precipitation grids when available from ENTRO and the ability to define stations for which data should be shared with ENTRO, the data types that should be shared, and the frequency of transmitting the data.

4.1.5.2 Current Status

There is currently no regional sharing other than the synoptic data that are made available by NMA to WMO as part of the global observation network. While there may be nearly 20 synoptic stations around the country, there are fewer than five stations within the Eastern Nile basin in Ethiopia that report to WMO on a daily basis. Previous efforts by NBI/ENTRO in obtaining approval for data sharing agreements and protocols have encountered difficulties.

4.1.5.3 Implications

Apart from the limited number of synoptic stations in the Eastern Nile basins of Ethiopia that are reported to WMO, there is neither a systematic data sharing protocol nor systems in place to facilitate data sharing with other EN countries through a link with ENTRO. The Ethiopian component of the data sharing protocols and technologies need to be developed.

4.1.6 Institutional Setting

4.1.6.1 Desired outcome

An effective flood forecasting and warning program usually includes a dedicated forecasting center with a clear mission and organizational mandate. Available staff resources should include at a minimum two hydrologic forecasters, a hydrometeorological forecast specialist, and a computer systems expert. All should be cross-trained to be able to support one another during absences from the office and during emergencies when 24 hour operations are required and staff must rotate shifts. Operators should understand how to keep the system running in the absence of some expected data inputs, but should appreciate the implications for accuracy of the system

During seasons of heavy precipitation, there should be some anticipation of potential extreme weather based on meteorological forecasts to permit extra staffing to be available outside of normal working hours to monitor and respond to hydrologic events. There should be sufficient trained staff to permit 24 hour operation for short periods of time during emergencies. At least 4 trained forecasters, including backup staff who may normally work in a different function, should be available during critical seasons to rotate forecast duties during emergencies.

The forecast center will normally be supported by separate program for hydrometeorological monitoring that is responsible for maintaining the data collection network and telecommunications system. Available staff resources should include a telecommunications specialist, a computer systems expert, and two hydrographers. In addition to staff based at the data collection center, the monitoring program also needs local staff at monitoring sites to provide security for the equipment and to be able to follow simple instructions for equipment analysis, maintenance and repair. This will reduce the risk of vandalism and will increase the efficiency of station maintenance by reducing the travel burden on the hydrographers.

Adequate funding will be required to support the data collection program and the forecasting program, including both the staff positions as well as for travel, equipment, and spare parts.

Appropriate coordination is required between the NFC and the NMA to ensure that data collected by each are available to the other, and to plan deployment of automated networks in a way that avoids duplication

4.1.6.2 Current Status

The MOWE includes a hydrology department as well as the national meteorological authority which together direct the activities that would be likely to fall under a national data collection and hydrologic forecasting program. The hydrology department manages hydrometric data collection and archiving activities, including stream gauging for the purpose of establishing rating curves. It has regional and branch staff that are responsible to visit stream gauge sites for inspection and to make discharge measurements. There are also staff at the national center who are responsible for maintaining a database of historical stage and discharge data. Ethiopia has identified hydrologic regions, each of which has a regional staff that is responsible for maintaining stream gauges and collecting records and sending them to the national staff in Addis. In addition to regional staff, there are individual observers who are paid a modest amount to make observations of water levels at existing stations. The regional staff in Bahir Dar report that resources are not sufficient to adequately maintain gauges or make sufficient discharge measurements to maintain rating curves. There are insufficient staff and equipment resources to take measurements frequently enough to capture peak flows.

Meteorological stations are maintained by the NMA, which also has a national center staff that gathers and archives data, visits stations at least annually, and manages both the real-time and historical data processing and storage. NMA also has a distributed network of paid observers who make daily meteorological observations. The NMA supports a staff that prepares weather forecasts and operates numerical weather prediction models. NMA staff identified that there is currently no agreement in place that obligates them to share data, particularly in real-time, with other agencies, including the hydrology department.

The general telecommunications and electric power infrastructure are important aspects of the context in which the systems that are the subject of this study will operate. The consultant's first hand experience in Ethiopia is that electric power is available in all developed regions and that it can be expected to be available a large percentage of the time. Interruptions of continuous power, however, are frequent and may last from a few minutes to several hours. These durations are longer than can be supported by common battery backup systems or uninterruptible power supplies (UPS), so UPS equipment will need to be coupled with emergency generators to keep critical systems in operation.

Data collection networks typically rely on telemetry systems to transmit data from remote locations to receiving facilities in developed areas, and internet for data communications within and between developed regions. The consultant has observed that internet access is widely available in developed areas of Ethiopia but that reliability is low and extended periods without access are common. Robust telecommunications solutions, therefore, may need to be independent of the national internet infrastructure.

The service areas for cellular data transmission using GSM/GRPS networks is limited to developed areas, which may be acceptable for stream gauges located in populated areas, but will not be adequate for more remote stream gauging sites or for many of the precipitation gauges, which are located in remote areas to be able to adequately cover the spatial extent of watersheds.

4.1.6.3 Implications

The MOWE is generally organized with the necessary functional areas to support hydrometric and meteorological data collection, but there are specific gaps in capability as follows:

- Lack of available staff with training and experience in modern electronic monitoring stations and equipment (data loggers, electronic sensors, etc)
- Lack of available staff with training and experience in telecommunications
- Lack of available staff with training and experience in real-time data processing and computer networking
- Lack of available staff with training and experience in hydrologic forecasting and flood warning.
- Lack of an institutional mission within the hydrology department associated with real-time data collection and hydrologic forecasting and warning
- Lack of an institutional mission or assignment to provide meteorological data and forecasts (mainly precipitation) to the hydrology department for purposes of hydrologic forecasting.
- Insufficient regional staff, resources, and equipment to oversee and support regular gauge maintenance and regular stream gauging.

Closing these gaps will require training for existing staff, hiring and training additional staff, and establishing organizational missions and cooperative agreements among departments and agencies to assure the fulfillment of hydrologic forecasting and flood warning objectives.

4.2 Sudan

The principal flood forecasting challenge in ***Sudan*** is to predict riverine flooding along the Blue Nile, including communities upstream of the Sennar Dam as well as the densely populated areas of Wad Medani, Hasahisa, and Khartoum downstream of the Sennar Dam. Other areas include key locations along the Main Nile, including the confluence with the Atbara river and the downstream site at Dongola. Sudan also has several important dams along the Blue Nile (Roseires, Sennar, Merawi) and on the Atbara (Kashem El Girba Dam) as well as a dam under construction (Setit Dam) upstream of the Girba Dam on the Atbara River. Inflow forecasts for these reservoirs could aid in reservoir operations for both flood control and water management. Forecasting is also needed for the floodplains of the Sobat River, which also drains a significant area that originates in Ethiopia. Although heavy rainfall and a corresponding hydrologic response may be observed in areas near the Ethiopian border, precipitation drops off dramatically in the vicinity of the Blue Nile and Main Nile rivers within Sudan. The need for a dense network of precipitation stations, therefore, is reduced with distance from the Ethiopian border. The river response tends to be more gradual along the Blue Nile, resulting in a different timing dynamic than in Ethiopia, with response times of several days to a week in many cases.

To provide the best possible lead times and forecast accuracy, Sudan would benefit from:

- Observations and estimates of precipitation throughout the Ethiopian highlands and border regions in Sudan, including the Blue Nile (Abbay), Atbara (Tekeze) and Baro-Akobo river basins;
- Stream gauges observations at main river gauges.

The gap analysis concludes with a review of the missing elements of the desired capabilities and outcomes for hydrologic forecasting and flood warning in Sudan. This section provides only a brief list of the elements that are missing. It is noted here that Sudan does, in fact, possess some forecasting capability that in which the current technologies are matched with one another to produce the current capability. The gaps identified below are those that must be closed across multiple aspects of a forecasting program for improvement and for achievement of the desired outcomes identified above.

4.2.1 Desired Outcome

Sudan will continue to centralize forecasting functions at a national forecast center (NFC) within the MOIWR in Khartoum. All data transmissions from the data collection network, therefore, need to be directed to the forecast center for processing.

4.2.2 Hydrologic Forecasting

4.2.2.1 Desired outcome

Data inputs - the desired forecast capability will include the ability to accept and integrate the following inputs in real-time:

- Observed water level
- Observed discharge
- Observed point precipitation
- Gridded precipitation estimates (from radar or satellite)
- Forecast precipitation (usually a gridded input)
- Observed reservoir inflows, outflows, and pool elevations

Pre-processing – The system will need to be robust and flexible to permit forecasts to be developed even when some inputs are not available, especially those inputs where missing data are not uncommon or not essential, including missing station observations. Pre-processing functions may permit missing data to be estimated as necessary to perform hydrologic simulations.

Hydrologic simulation – a flexible framework for simulating hydrologic phenomenon, including rainfall-runoff, stream routing, and reservoir simulation is required. Because the rainfall –runoff response is non-linear and is dependent on initial conditions, a continuous model that accounts for variation in soil moisture based on antecedent precipitation observed in the system may be desirable. The system will need to be able to store and retrieve copies of model states for use in simulating with the continuous model.

Incorporation of observed streamflow – there will always be differences between observed and simulated streamflow. Where there is high confidence in streamflow observations, the system should be able to incorporate observed streamflow into the hydrologic simulation so that downstream routing algorithms are using the best available inputs. This is of special interest in Sudan, where water level is the most important observation that can be measured directly within the country. Reliable and frequently updated rating curves will be required to accurately determine the streamflow based on a water level observation.

Forecast points – the nature of most hydrologic forecast systems requires alignment between multiple factors associated with the locations of forecasts, including:

- Location of real-time observed streamflow, which is vital for verifying forecasts
- Subdivision of basins both to permit a forecast at a specific point, as well as to properly model the spatial variability of hydrologic response to rainfall
- Locations where forecasts are needed, such as at areas where flooding of population and infrastructure is likely or above water control structures that require forecasts for improved operation;
- Locations of water control infrastructure that both modifies and functions in response to upstream runoff hydrographs.

Forecast points are located to meet forecast needs and balance these considerations. For Sudan this will mean carefully selected forecast points as follows:

- At key sub-basin divisions within Ethiopia where spatial variation in precipitation and response can be represented and where streamflow observations will be available for verification;
- At border locations where direct monitoring of streamflow originating in Ethiopia will be available in Sudan;
- At key populated areas and reservoirs on the Blue Nile and Main Nile rivers;
- At key populated areas and reservoirs on the Atbara, Dinder and Rahad rivers;
- At river confluences.

Automated execution – Although the major forecasting requirements can be met with manual operations on a daily basis, it may be desirable to have a system with flexibility to include some automated simulations and warnings based on events observed at automated stations, such as precipitation observations or water level rises above a threshold within a given period of time. These features might be activated in the future for specific regions where shorter lead times exist. To be effective this capability needs to be coupled with the capacity for frequent ingest and simulation, on the order of once per hour. For the majority of the forecast points, however, the lead time will be sufficient to permit waiting for manually initiated simulation.

Forecast adjustments – For larger basins it is beneficial to be able to take advantage of the available lead time to make adjustments to forecast simulations so that they better match observed streamflow.

This can be done by increasing or decreasing the input precipitation pattern or adjusting initial conditions, for instance.

Hydraulic simulation – Where rivers have gentle slopes, backwater from reservoirs, and major confluences, it can be difficult to estimate peak discharges and the extent of flooding based solely on hydrologic inputs. Hydraulic models will be required to permit a more accurate simulation of routing in the channel and to produce a precise estimate of river profile and extent of flooding, especially when coupled with the ability to define inundation extent based on real-time prediction of water levels. This will be important along the Blue Nile and Main Nile rivers.

Reservoir operations – For both small and large river basins with reservoirs, a reservoir simulation component will be helpful to be able to represent the effect of flood storage and release on the shape of the discharge hydrograph as it moves through reservoirs in the river system. The essential feature of the reservoir model is to be able to simulate reservoir storage, elevation, and outflow based on inflow and reservoir operating rules, allowing a forecaster to manually define outflows to override the operating rules as needed. The capability envisioned here is not intended to dictate the operation of the reservoirs, but to predict them.

Operational integration – The components that comprise the forecast system should operate together in an integrated fashion with an operational focus. This means that certain repetitive processes are automated, the components communicate with one another or with a central database so that manual intervention is kept to a minimum, and system is robust so that operations can proceed even in the absence of some of the expected data inputs.

Precipitation forecasts – Precipitation forecasts may be of value for Sudan, especially for Nile tributaries where there is reduced lead time between observed precipitation and arrival of runoff peaks at flood prone areas. The development of precipitation forecasts is usually the responsibility of a meteorological agency which produces the outputs in a form that can be ingested by the forecast system. This process will serve flood forecasting needs best if it is reliable and smoothly integrated with the hydrologic forecast system.

Notification/dissemination – The forecast system capability typically extends to the development of products (graphics, tables, and text) that describe the forecasted conditions. A complete forecasting program will also include the subsequent protocols, procedures and associated tools necessary for notification to the responsible staff of critical conditions, and the dissemination of forecasts and warnings to the affected population.

4.2.2.2 Current Status

A hydrologic forecast system was established previously in Sudan using the Delft (now Deltares) FEWS system. Over time the forecast system lapsed into disuse, with all of the automated stations that were implemented to provide data to the system having ceased operation. Two recent project supported by ENTRO have developed a hydrologic model (using HEC-HMS) for the entire Blue Nile basin, including the portions of the basin in Ethiopia, and a hydraulic model (using HEC-RAS) for the Blue Nile from Eddiem to Khartoum. With assistance from ENTRO, Sudan is restoring and upgrading its previously implemented hydrologic forecast system, which will provide a new user interface and integrate the hydrologic and hydraulic models. It is not clear how the upgraded forecast system will receive and ingest forecast and observed precipitation data or observed streamflow data.

ENTRO also publishes a flood bulletin covering both Ethiopia and Sudan which includes longer term indicators of potential flooding conditions based on seasonal climatic factors

4.2.2.3 Implications

The current forecasting capability in Sudan lacks the following elements:

- Observed data inputs from the Ethiopian highlands (precipitation, water level, discharge, reservoir elevations)
- Spatial precipitation from satellite or radar
- A continuous hydrologic model capable of managing model states
- Reservoir simulation component
- Notification/dissemination
- A hydraulic model that includes the White Nile and the Main Nile below the confluence, extending to Dongola.

Because the forecast system enhancements that are being undertaken are concurrent with this study, it is difficult to accurately assess the outcomes for this report. In particular it is not clear how data from the existing manually operated network will be integrated into the system; how hydrologic simulation will be conducted without observed data from the Ethiopian highlands, or if there is a plan to incorporate precipitation forecasts into the overall system. While the forecast system framework includes a suite of advanced capabilities, it is not clear how many of these features will be implemented in the system that is being prepared.

4.2.3 Data Collection Network

4.2.3.1 Desired Outcome

The data collection network is described by the location of data collection stations, the specific parameters that are measured at each location, and the sampling interval, storage, and transmission capabilities of the station. For purposes of this analysis the data collection network includes the sensors, data loggers, battery and power supplies, but excludes the telemetry system which is discussed separately.

Precipitation – At the core of hydrologic forecasting is the potential to predict the runoff response of a basin to precipitation. It is the existence of a delay or lag between the occurrence of precipitation and the arrival of the resulting runoff that permits action in response to the expected runoff. Measurement of precipitation throughout a river basin is therefore fundamental to the development of forecasts.

To produce accurate forecasts, the precipitation network needs to be dense enough to represent the spatial variability of rainfall throughout the basin of interest. Small basins require a higher network density than large basins. Likewise, areas where runoff is dominated by convective storms require a higher network density than areas where major runoff is produced by synoptic rainfall. The predominance of synoptic rainfall during the flood season in the Eastern Nile suggests the need for a broad network of distributed precipitation stations near the border areas within the Blue Nile, Atbara, Dinder and Rahad rivers.

The precipitation stations should be able to sample rainfall data at hourly intervals and store the data for an extended period (several months) to permit manual data rescue at the station in the event that telecommunications equipment fails for any reason.

Hydrometric Network – observations of water level at locations with reliable discharge rating curves are essential for verifying the accuracy of forecasts in real time, as well as for subsequent calibration of models. In Sudan water level observations are of heightened importance because most of the runoff-producing precipitation occurs beyond its borders and its direct ability for measurement. Streamflow observations become the critical dependable basis for downstream forecasts.

Streamflow stations with water level sensors are generally located at all forecast points, where conditions permit. Conversely, forecast points may be limited to locations with active streamflow stations. The streamflow stations should be able to sample water level data at hourly intervals and store the data for an extended period (several months) to permit manual data rescue at the station in the event that telecommunications equipment fails for any reason.

Weather – Weather stations are needed to support the functioning of numerical weather prediction models that are used to provide precipitation forecasts. The station density will be less than the precipitation network, but greater than the synoptic network of data that are provided to the WMO. Station parameters include temperature, relative humidity, wind speed and direction, and solar radiation. These data need to be available to the NMA (or whoever will provide the precipitation forecast input to the system).

Station infrastructure – in addition to the parameters to be measured, each station needs to be robust and secure. Critical components include the following:

- Power supply – including solar panels, batteries, and cables designed to support power demands of all electronics based on expected available sunlight.
- Lightning protection, including lightning rods and grounding equipment
- Security – secure fencing, and locking hardware cabinets
- Mast – a tower on which to mount solar panels, sensors, and antennas for telemetry at appropriate heights
- Data logger with appropriate storage and programming capability to manage data transformations and transmissions.
- Telemetry (discussed below)

4.2.3.2 Current Status

A long term data collection network exists in Sudan, including a meteorological network operated by the NMA and a hydrometric network operated by the MOIWR.

Precipitation - The existing precipitation network is part of the climatic network of the NMA. Officials stated that only a limited number of stations in the network report data to NMA headquarters on a daily basis. The remainder are climatic stations where observations are only available as frequently as NMA staff visit the site to collect the records. The observations are made manually on a daily basis by observers.

Hydrometric Network – The hydrometric network is operated by the MOIWR. Stations are typically equipped with a stone or concrete staff gauge that is read manually by an observer. Some stations are equipped with radios so that the observer can report daily measurements to MOIWR in Khartoum. Discharge measurement equipment is maintained locally at some sites and varies from current meters on bank operated cableways to current meters operated from boats.

It is notable that Egypt operates a number of river gauges on the Blue Nile and its tributaries in Sudan.

Weather Stations – The NMA in Sudan operates several classes of weather or climate stations among its network of over 1000 stations noted above under precipitation. The primary distinction between the classes is the number of meteorological parameters being measured. Class 1 stations measure all major parameters and class 3 stations may only measure precipitation and temperature. These stations provide daily reports. In addition there a small number of synoptic weather stations that provide reports on a 3-hour basis. These data are transmitted regularly to the WMO as part of its global observation network.

A field tour was conducted to visit representative sites, including many candidate sites for high priority implementation of automatic gauges. A field report is included as Appendix B. Important conclusions regarding the stations and the network are that the facilities and technology for streamflow and climate data measurement and observations have not changed substantially over the past several decades. The condition of staff gauges has deteriorated and has not been maintained in many cases. Siltation of staff gauges is a frequent problem.

4.2.3.3 Implications

The existing data collection network is based on station equipment and sensors that are not compatible with automated data logging and telemetry systems. There is a general lack of credibility such that MOIWR staff are not always certain if the reported gauge observations are real or fabricated, and they desire an automated system that is less dependent on continuous human judgment and initiative. Therefore, any station that is selected as part of the real-time network will require upgrading of hardware and infrastructure, including sensors, data loggers, solar panels, batteries, cables, masts and any associated civil works.

4.2.4 Telemetry

4.2.4.1 Desired Outcome

The desired telemetry system is described separately from the data collection network because there are multiple options and associated tradeoffs that are mostly independent of decisions regarding the network layout and selection of sensors at various sites. The principal needs are as follows.

Reliability – the telemetry system needs to be available during critical conditions, when severe weather is occurring, when conventional means of communication may be stressed due to emergencies, or when power outages exist.

Reporting frequency – the telemetry system must be able to provide transmission of data at the reporting frequency required for the type of data, size of the basin, and forecasting requirements. Hourly transmissions should be acceptable for small basins, and three to six hour transmissions (or even daily) may be acceptable for larger basins.

Security – the telemetry system needs to be secure such that it is protected from interference. Sudan is open to telemetry options that leverage local, regional and international infrastructure investment.

Flexibility – it may be important for the telemetry system to allow flexible definition of transmissions, so that more frequent transmissions may be made from stations in small basins and during seasons of heavy precipitation, with a reduced frequency during dry periods.

4.2.4.2 Current Status

The hydrometric station network operated by the hydrology department uses Low Frequency (LF) radio and cell phones to permit remote site staff to communicate by voice to report manually observed data to Khartoum.

It is not clear what type of telemetry is used for the climate network operated by NMA.

4.2.4.3 Implications

There is no functioning telemetry system in Sudan capable of providing automated real-time data inputs to a hydrologic forecast system. What does exist is limited by timeliness and reliability (the manual radio/cellular telemetry system). A comprehensive telemetry system is therefore required to achieve the desired outcomes.

4.2.5 Data Processing and Storage

When the observed data are transmitted to a central location, important processing functions take place. These functions are performed automatically and require that the receiving base station be available full time as a mission critical system. Failure of the system for even a short period of time can result in critical losses of information. This requires a robust power source with uninterruptible power supplies and backup power generators.

Precipitation data need to be processed to hourly accumulations at each station for use in the forecast system. Water level at river gauges should be processed through rating curves to yield estimates of hourly instantaneous discharge. A map display should be provided that permits a visual representation of the network with numerical and graphical depictions of recent observations of all parameter types. The data processing and forecast systems should permit close coupling to facilitate automated operation for small basins, as well as manual forecast execution for larger river basins.

The processing system should allow storing several months of observations, with tools for exporting the data to files or other systems for archival purposes. This permits the database to be optimized for real-time operations while permitting the data to be used subsequently for development of a historical climate and streamflow database.

The data processing workstation should be configured with a separate backup workstation with regular mirroring of data that can be quickly and easily configured to receive and process data.

4.2.5.1 Current Status

The MOIWR receives data reports by radio from the network of hydrometric stations, but it is not clear that there is any formal data processing and storage system other than spreadsheets into which the data are entered. Staff operating the forecast system manually copy observations and put them into the hydraulic model.

It is not clear how NMA staff process and store real-time observed data for climate and weather station data.

4.2.5.2 Implications

There is currently only a manual data processing capability for hydrometric and meteorological data. This capability is not compatible with real-time telemetry systems nor with the envisioned forecasting capability. A comprehensive data processing system is therefore required.

4.2.6 Regional data sharing

Because Sudan is situated downstream of the major runoff producing areas in Ethiopia and upstream of the High Aswan Dam in Egypt, it is in a pivotal situation regarding data sharing. Elements of data sharing that may be of interest to Sudan are:

- Providing data to other EN countries as part of a general interest in outreach for reducing improving water management in the EN region.
- Receiving meteorological data from other countries for numerical weather prediction models;
- Receiving precipitation and streamflow observations from Ethiopia for use in hydrologic model simulation;
- Receiving Satellite precipitation estimation grids from the Nile Forecast Center in Egypt; and
- Providing precipitation data to Egypt to improve the satellite precipitation estimation grids.

It is assumed that data sharing would be organized by ENTRO, with each EN country providing data to ENTRO, which would then host a service from which each country download desired data. From this perspective, the important features of a data sharing system in Sudan are the ability to automatically retrieve weather data and precipitation grids when available from ENTRO and the ability to define stations for which data should be shared with ENTRO, the data types that should be shared, and the frequency of transmitting the data. Because of its historically close relationship with Egypt in Nile water management, options for direct cooperation in data sharing with Egypt might be advantageous.

4.2.6.1 Current Status

Discussions with Sudanese and Egyptian staff implied that the data from one another's networks was available to each country, but it was not clear how the exchange of data occur. Officials at the NMA indicated that there was once a cooperative project between Ethiopia and Sudan that led to a regular sharing of data, but some time after the project concluded data transmissions also were discontinued.

Synoptic data are made available by NMA to WMO as part of the global observation network. Data from surrounding countries should be available to Sudan from WMO.

4.2.6.2 Implications

Apart from a limit number of synoptic stations reported by Eastern Nile countries to WMO, there is neither a systematic data sharing protocol nor systems in place to facilitate automated data sharing with other EN countries, either through a link with ENTRO or through bilateral exchange. There are cooperative relationships between Sudan and Egypt that permit Egypt to operate stream gauging sites in Sudan and that facilitate data exchange between the countries. These are not adequate to support real-time forecasting, but could form the basis for automated data sharing agreements in the future. The Sudanese component of real-time data sharing protocols and technologies needs to be fully developed.

4.2.7 Institutional Setting

An effective flood forecasting and warning program usually includes a dedicated forecasting center with a clear mission and organizational mandate. Available staff resources should include at a minimum two hydrologic forecasters, a hydrometeorological forecast specialist, and a computer systems expert. All should be cross-trained to be able to support one another during absences from the office and during emergencies when 24 hour operations are required and staff must rotate shifts. Operators should understand how to keep the system running in the absence of some expected data inputs, but should appreciate the implications for accuracy of the system

During seasons of heavy precipitation, there should be some anticipation of potential extreme weather based on meteorological forecasts to permit extra staffing to be available outside of normal working hours to monitor and respond to hydrologic events. There should be sufficient trained staff to permit 24 hour operation for short periods of time during emergencies. At least 4 trained forecasters, including backup staff who may normally work in a different function, should be available during critical seasons to rotate forecast duties during emergencies.

The forecast center will normally be supported by separate program for hydrometeorological monitoring that is responsible for maintaining the data collection network and telecommunications system. Available staff resources should include a telecommunications specialist, a computer systems expert, and two hydrographers. In addition to staff based at the data collection center, the monitoring program also needs local staff at monitoring sites to provide security for the equipment and to be able to follow simple instructions for equipment analysis, maintenance and repair. This will reduce the risk of vandalism and will increase the efficiency of station maintenance by reducing the travel burden on the hydrographers.

Adequate funding will be required to support the data collection program and the forecasting program, including both the staff positions as well as for travel, equipment, and spare parts.

Appropriate coordination is required between the NFC and the NMA to ensure that data collected by each are available to the other, and to plan deployment of automated networks in a way that avoids duplication

4.2.7.1 Current Status

The MOIWR includes a hydrology department as well as the national meteorological authority which together direct the activities that fall under a national data collection and hydrologic forecasting program. The hydrology department manages hydrometric data collection and archiving activities, including stream gauging for the purpose of establishing rating curves. It has a national staff that is responsible to visit and provide maintenance at stream gauge sites, as well as local staff at each site that is responsible for making water level observations and making discharge measurements. There are also staff at the national center who are responsible for processing and managing data from the real-time hydrometric network. Finally, the MOIWR includes two forecasters who operate the forecast system, including maintaining a backup of a numerical weather model that is officially operated by the NMA.

Ministry staff indicate that there is concern about the reliability of observations, especially when the stream gauge is far from the observer’s dwelling, and there is a tendency to estimate readings rather than make actual observations.

Meteorological stations are maintained by the NMA, which also has a national center staff that gathers and archives data, visits stations, and manages both the real-time and historical data processing and storage. NMA also has a distributed network of paid observers who make daily meteorological observations. The NMA supports a staff that prepares weather forecasts and operates numerical weather prediction models. NMA officials indicated a willingness to share data and forecasts, particularly in real-time, with MOIWR.

The general telecommunications and electric power infrastructure are important aspects of the context in which the systems that are the subject of this study will operate. The consultant’s first hand experience in Sudan is that electric power is available in all developed regions and that it can be expected to be available a large percentage of the time. Interruptions of continuous power, however, are a risk that should be accommodated in a fully developed infrastructure. Common battery backup systems or UPS equipment will need to be coupled with emergency generators to provide maximum reliability.

Data collection networks typically rely on telemetry systems to transmit data from remote locations to receiving facilities in developed areas, and internet for data communications within and between developed regions. The consultant has observed that internet access is widely available in developed areas of Sudan.

The service areas for cellular data transmission using GSM/GRPS networks is broadly available at many, but not all stream gauging sites. Service is less likely for remote stream gauging sites and for many of the precipitation gauges, which are located in remote areas.

4.2.7.2 Implications

The MOIWR is generally organized with the necessary functional areas to support hydrometric data collection, and the NMA for meteorological data collection, but there are specific gaps in capability as follows:

- Lack of available staff with training and experience in modern electronic monitoring stations and equipment (data loggers, electronic sensors, etc)
- Lack of available staff with training and experience in telecommunications
- Lack of available staff with training and experience in real-time data processing and computer networking
- Lack of available staff with training and experience in hydrologic forecasting and flood warning.
- Lack of an institutional mission or assignment for NMA to provide meteorological data and forecasts (mainly precipitation) to MOIWR for purposes of hydrologic forecasting.

Closing these gaps will require training for existing staff, hiring and training additional staff, and establishing organizational missions and cooperative agreements among departments and agencies to assure the fulfillment of hydrologic forecasting and flood warning objectives.

4.3 Egypt

The forecasting challenge in ***Egypt*** is to be able to accurately predict seasonal inflows to the High Aswan Dam, which drains the entire area of the White Nile, Blue Nile, and Main Nile watersheds. Egypt has a highly developed hydrologic forecasting capability but lacks key information regarding upstream conditions beyond its territory. The following gap analysis focuses on the components that require attention, with only brief mention of desired capability that is already available in the mature system that it operates.

4.3.1 Hydrologic Forecasting

4.3.1.1 Desired outcome

Beyond existing capabilities, desired outcomes for Egypt would include reservoir models to reflect the operations of newly constructed reservoirs upstream of HAD.

4.3.1.2 Current Status

Egypt centralizes forecasting functions at the Nile forecast center (NFC) within the MOWRI. The forecast system integrates satellite based precipitation estimates, observed precipitation, and observed streamflow. It provides for processing of observed inputs for use in the system. The hydrologic simulation component is based on a continuous soil moisture accounting model that keeps track of model states for use in ongoing simulations. The Egyptian forecast concern leads to the need for a single forecast point, although the upstream watersheds are subdivided to permit improved representation of the watershed for more accurate forecasts. Observed streamflow can be incorporated into both downstream routing as well as updating upstream soil moisture conditions. It includes the ability to simulate reservoirs and lakes.

Egypt has a well developed hydrologic forecast environment that generally meets its current needs.

4.3.1.3 Implications

Egypt lacks a simulation of reservoir operations at the Tekeze dam on the Tekeze river in Ethiopia and the Merawi Dam on the Main Nile in Sudan in its forecast system.

4.3.2 Data Collection Network

4.3.2.1 Desired Outcome

Because the inflows to HAD are from outside of Egypt there are no stations within Egypt that are of importance in the development of inflow forecasts for the dam. Egypt does operate a number of streamflow gauges on the Blue Nile in Sudan. Desired outcomes would be to have modern automated measurement of water level from these stations. The criteria for these stations would be the same for streamflow gauges operated by Sudan.

4.3.2.2 Current Status

Egypt operates a network of stream gauges with manual observers in Sudan. Characteristics are equivalent to the network operated by Sudan.

4.3.2.3 Implications

Egypt’s network of hydrometric gauges in Sudan are not compatible with automated data logging and telemetry systems. Therefore, any station that is selected as part of the real-time network will require upgrading of hardware and infrastructure, including sensors, data loggers, solar panels, batteries, cables, masts and any associated civil works.

4.3.3 Telemetry

It is anticipated that telemetry needs for gauges within Sudan should be analogous to needs for stations maintained by Sudan.

4.3.3.1 Current Status

For Egypt's monitoring network in Sudan, the telemetry should be the same as for those operated by Sudan. There is, however, a meteor burst base station at the High Aswan Dam that could potentially be used in the region for receiving remote station reports and then transmitting them through the internet.

4.3.3.2 Implications

There is no functioning telemetry system installed on Egypt's hydrometric stations in Sudan that is capable of providing automated real-time data inputs to a hydrologic forecast system. A comprehensive telemetry system would be required to achieve the desired outcomes.

4.3.4 Data processing and storage

4.3.4.1 Desired outcome

Egypt's data processing needs are associated with the regional data sharing component, inasmuch as the required data originate outside of the country. Important functions are the ability to pass data received from the regional data sharing component to the forecast system.

4.3.4.2 Current Status

The NFC in Egypt currently has data processing capability that permits downloading and incorporating WMO data reports from other EN countries into its forecasting procedures, including both meteorological and hydrologic forecasting.

4.3.4.3 Implications

The current data processing and storage system seems adequate for current needs, but lacks the ability to automatically incorporate regional data from ENTRO if it became available.

4.3.5 Regional data sharing

4.3.5.1 Desired Outcome

Because the High Aswan Dam in Egypt is situated downstream of the major runoff producing areas in Ethiopia and Sudan, regional data sharing is potentially very important to Egypt. Elements of data sharing that may be of importance to Egypt are:

- Receiving precipitation and streamflow observations from Ethiopia and Sudan for use in hydrologic model simulation and to improve the satellite precipitation estimation grids;
- Providing satellite precipitation estimation grids to the other EN countries;

It is assumed that data sharing would be organized by ENTRO, with each EN country providing data to ENTRO, which would then host a service from which each country download desired data. From this perspective, the important features of a data sharing system in Egypt are the ability to automatically retrieve precipitation and streamflow observations when available from ENTRO and the ability to share precipitation grids with the other countries.

4.3.5.2 Current Status

Discussions with Sudanese and Egyptian staff implied that the data from one another's networks was available to each country, but it was not clear how the exchange of data occur. Synoptic data are made available by NMA to WMO as part of the global observation network. The NFC uses data from the WMO to enhance meteorological forecasts and to improve satellite precipitation estimates.

4.3.5.3 Implications

Apart from a limit number of synoptic stations reported by Eastern Nile countries to WMO, there is neither a systematic data sharing protocol nor systems in place to facilitate automated data sharing with other EN countries, either through a link with ENTRO or through bilateral exchange. There are cooperative relationships between Sudan and Egypt that permit Egypt to operate stream gauging sites in Sudan and that facilitate data exchange between the countries. These are not adequate to support real-time forecasting, but could form the basis for automated data sharing agreements in the future. The Egyptian component of real-time data sharing protocols and technologies needs to be fully developed.

4.3.6 Institutional setting

4.3.6.1 Desired Outcome

Egypt's hydrologic forecasting and associated supporting institutions are well developed. Desired capacity that might grow out the recommendations of this study would include stronger arrangements with ENTRO and other countries to support and strengthen data collection and sharing activities there.

4.3.6.2 Current Status

Egypt's hydrologic forecasting and associated supporting institutions are well developed.

Egypt has a well developed technological infrastructure, including reliable electric power and internet connectivity. In addition, Egypt has several meteor burst telecommunications systems that have the potential to be used for telemetry in surrounding areas extending throughout the EN river basin.

4.3.6.3 Implications

Egypt needs stronger arrangements with ENTRO and other countries to support and strengthen data collection and sharing activities there.

4.4 ENTRO

ENTRO's role in this endeavor is to facilitate regional data sharing with a data exchange center, to provide technical support, and to provide logistical support in procurement. The analysis below focuses on ENTRO's ability to facilitate the data exchange and technical backstopping.

4.4.1 Data Processing and Storage

ENTRO's data processing and storage functions will be based on the requirements of the regional data sharing component discussed below.

4.4.2 Regional Data Sharing

4.4.2.1 Desired Outcome

ENTRO will have a data sharing system that permits EN countries to automatically send real-time data to be held in the system for retrieval by other EN countries. The system should permit both visual review and download of the data as well as automated query and download of new or changed data from other EN country data systems. It will need to support observed station data for water level, precipitation, and assorted meteorological parameters. It will also need to support gridded precipitation data formats.

The system would have a web-based data review and download component, as well as an automated component for upload and download. A data management interface will be needed to permit station definitions and configuration of the data communications interface.

4.4.2.2 Current Status

ENTRO currently hosts a web-page and posts current results from an ETA numerical weather prediction model during the course of the flood season. This is a view only web-site and does not support the download of any underlying data.

4.4.2.3 Implications

A complete data sharing system will be required to provide the desired outcome. The current availability of high-speed internet connectivity and the current practice of posting current model results indicates the existence of some of the required infrastructure components that will be needed.

4.4.3 Institutional Setting

4.4.3.1 Desired Outcome

ENTRO will provide support and training in forecasting, data collection, telemetry, data processing and storage. ENTRO can facilitate these activities by contracting with both local and international consultants and providing facilities and logistical support for training activities, This will require ENTRO to have staff or to have contractors available that are experienced in all of these activities. It will also require staff with capability in program management, international bidding processes, and contract management, both to manage ENTRO procurement activities as well as to support the EN countries in coordinated procurement and contracting.

To support the real-time data communications system ENTRO will need staff with experience in computer systems and hydrometeorological data management, although these resources may be shared among other related program functions within ENTRO. A reliable, high-speed internet connection will be required, together with reliable power supply to maintain operational capability. Meteorological and hydrologic phenomenon associated with flooding occur irrespective of working days and hours. It is expected that the national data processing systems will be configured to both send and receive data transmissions at timed intervals that occur throughout the day and night. It will be required that ENTRO maintain 24-hour operational capability of the data sharing system so that there are no gaps in data reception from the national data centers. If the infrastructure environment in which ENTRO operates makes it impossible to provide reliable 24-hour data communications, then additional functionality will be required of the data sharing system at ENTRO and in each of the EN countries to assure that data transmissions that may have been attempted during down times are repeated so that data reports are not missed.

4.4.3.2 Current Status

ENTRO is currently organized to effectively execute projects and activities in support of development in the Eastern Nile region. These activities include a significant contracting component to access international companies and consultants to provide services, perform studies, develop designs, and provide training and support to ENTRO and the EN countries. Recently ENTRO has engaged staff and a contractor in running operational models for numerical weather prediction, hydrologic forecasting, hydraulic simulation, and flood mapping. It performs these activities with collaboration and support from local experts, primarily associated with universities. These activities include the preparation of a flood bulletin that outlines current conditions and forecasts in the Eastern Nile basin.

ENTRO has an effective contracting office with a contracting officer and support staff, in addition to program coordinators and support staff that perform these functions.

ENTRO is equipped with high speed internet access through the Ethiopian Telecommunication Corporation (ETC), which provides all telecommunications services throughout Ethiopia. The network experiences periodic failures marked by complete or near complete loss of bandwidth. It has been observed that these failures result in loss of connectivity both within Ethiopia as well as between Ethiopia and other geographical areas. Anecdotal experience indicates that these failures occur several times per week and may last from less than an hour to nearly 24 hours, with typically outages of several hours.

Because the local national power grid also has regular power outages, ENTRO is equipped with an electric generator that automatically starts when there is a loss of power. Computer equipment within ENTRO is typically equipped with uninterruptible power supplies that bridge the gap in power that occurs prior to startup of the generators. It is not clear if the generators are configured to operate in a 24-hour mode or only during office hours.

4.4.3.3 Implications

ENTRO's historical role has not included an operational mission as a major component of its activities. operations. In order to be effective in facilitating data communications among the EN countries with a regional data collection and dissemination system, ENTRO will need to clearly articulate its commitment to staffing and operating a data communications center with a time horizon that is sufficient to demonstrate the value of this function to the EN countries. ENTRO lacks a data collection and management expert, but resources seem to be available either to hire or contract for these services or to provide training necessary for existing staff to take on these functions.

Although the RFCU has been discontinued, much of its staff has been retained by ENTRO either through incorporation into other elements of the organization or through retention as consultants. This has permitted continuity in flood coordination functions and in the project background that will be necessary to establish and maintain a regional data center. The associated staff have also performed effectively in minimizing the disruption that might otherwise have been associated with the discontinuation of the RFCU. Continued emphasis is needed on the part of ENTRO to demonstrate support for the flood coordination function, to clearly articulate its ongoing goals and objectives, and to clarify responsibility for flood coordination in the organizational structure.

ENTRO's operating environment appears to be equipped with appropriate electric power reliability. Maintaining a data sharing center will require existing facilities and new installations to be configured to provide 24-hour operations. Because internet connectivity has not historically been completely reliable and an independent satellite-based internet connection has not been approved by ETC, accommodations will be required to permit redundant data communications to assure that data from failed transmissions can be re-transmitted when connectivity is available.

5. Network Design Considerations

This chapter presents background information regarding many aspects of data collection systems that can be helpful in identifying appropriate selections for technologies to be applied to meet specific needs and objectives relative to a specific environment.

5.1 General

In order to develop a reliable network that satisfies the requirements of the individual countries, separate network designs will be developed for Ethiopia and Sudan. This will allow for networks that can be designed to meet its own specific requirements and allows each country full control over its network.

The regional sharing of data will be provided by a data connection between the national data collection networks and ENTRO. ENTRO will be set up to receive data sent by any of the three EN countries and to allow any of the three countries to download data from the complete database.

5.2 Forecast Points

Possible forecast locations in a flood forecasting network are the cities, town, or other locations that would benefit from a timely warning of a flood event. The warning will allow preparations to be made to limit the damage resulting from the flood as well as allow for evacuation of people and livestock to higher elevations.

Due to the broad impact of flooding, it is not feasible to include as a forecast point every location that might experience flooding. In an efficient network the forecast points will be strategically located throughout the basin to provide a warning to locations with economic importance or high population density. As noted previously, the nature of most hydrologic forecast systems requires alignment between the following factors associated with the locations of forecasts:

- Location of real-time observed streamflow, which is vital for verifying forecasts
- Subdivision of basins both to permit a forecast at a specific point, as well as to properly model the spatial variability of hydrologic response to rainfall
- Locations where forecasts are needed, such as at areas where flooding of population and infrastructure is likely or above water control structures that require forecasts for improved operation;
- Locations of water control infrastructure that both modifies and functions in response to upstream runoff hydrographs.

Forecast points also serve as calibration and verification points for the models used for the flood warning. This requires a hydrometric station at each forecast point. As such, the actual forecast point will need to be located at a site with hydraulic conditions suitable for a hydrometric station. This would mean that for a city in an alluvial fan, the location of the forecast point could be upstream of the impacted area where conditions are more suitable for a stream gauge. Suitability of hydraulic conditions is discussed in more detail in *Section 5.5, Hydrometric Site Location*. The appropriate location will permit forecasters to verify the forecasted results and provide for future calibration of the system.

To provide a forecast at a specific location, the effects of hydrologic inputs upstream of that location must be considered and the hydrologic modeling must be subdivided at that point. Because the basin upstream of a given point may include a large area with spatially variable precipitation and hydrologic response, additional subdivision of the upstream basin may be required to accurately simulate and forecast the combined response. Confidence in the forecast is improved when the upstream sub-basins are equipped with stream gauges to verify predicted response. These points are typically included as forecast points, even though there may be no specific population or infrastructure at risk.

In addition to locations of interest due to the need to warn populations or to know how to operate infrastructure, such as dams and canals, the infrastructure itself often has a major impact on the flood hydrograph, so that the model needs to be subdivided at that point, the effect of the infrastructure simulated, and the resulting hydrograph routed to downstream locations. These factors will influence the both the placement of automated stream gauges and the resulting location of the associated forecast points.

5.3 Automated Stations

5.3.1 Flow Measurement

Several option are available to measure flow in a river. Most of the available options will measure the water level in the river and determine the flow in the river based on a calibrated stage-flow rating curve. This paragraph lists the commonly available gauges that are suitable for use in a data collection system for flood forecasting.

5.3.1.1 Shaft Encoder

The shaft encoder (***Figure 5-1***) makes use of a stilling well alongside the river that is hydraulically connected to the river. A typical shaft encoder consist out of a float in the stilling well, connected by a line that runs over a pulley to a counter weight. The vertical motion of the float will result in a rotation of the pulley, which records the movement and forwards a signal to a data logger for interpretation of the signal.

<u>Advantages</u>: The Shaft Encoder is very commonly used to measure river stages. They have a long track record of satisfactory performance and are easily available from several manufactures.

<u>Disadvantages</u>: Shaft encoders require a stilling well for operation. The stilling well requires intake pipes that are located below the lowest expected flow during the life of the project. Special care should be taken to avoid drawdown of the water in the stilling wells in high velocity streams. The construction of a stilling well will increase the cost of the shaft encoder. Care should be taken that the stilling well does not fill up with sediment.

Figure 5-1: Shaft Encoder installation (left) and shaft encoder, battery and datalogger inside enclosure (right)

5.3.1.2 Submersible Pressure Water Level Sensor

The submersible Pressure Water Level Sensor is a pressure sensor that can be located in the river at the deepest point of the river. The Pressure sensor will measure the water pressure on the sensor and forward a signal through the attached cable to the data logger for interpretation of the water depth.

<u>Advantages</u>: The Submersible Pressure Water Level Sensor only requires the sensor, and the cable connecting the sensor to the hydrometric station to be located in the stream. This allows for most of the construction to be located outside the water.

<u>Disadvantages</u>: The sensor is located at the bottom of the stream and can be lost during high flow event. High flows could also result in a displacement of the sensor, resulting in inaccurate readings. Sedimentation can result in poor performance of the sensor.

5.3.1.3 Bubbler Water Level Sensor

A Bubbler Water Level Sensor (***Figure 5-2***) determines the water level indirectly by measuring the water pressure. It uses a gas-purge system to transmit the water pressure to the sensor by bleeding small amount of gas into a tube to an orifice in the stream. The pressure of the air in the tube is equal to the water pressure at the orifice location.

Advantages: Only a tube with an orifice is required in the stream, resulting in minimal construction in the stream and allows for most of the construction to be located outside the water. Normal sedimentation in a river does not negatively impact the accuracy of the bubbler water level sensor.

Disadvantages: Part of the installation is located at the bottom of the stream and can be lost during high flow events. High flows could also result in a displacement of the orifice, resulting in inaccurate readings.

Figure 5-2: single unit bubbler system (WaterLOG YSI incorporated, used by permission)

5.3.1.4 Ultra-Sonic Water Level Sensor

An Ultra-Sonic Water Level Sensor measures the time it takes for ultra-sonic waves to return to the sensor. The travel time of the ultra-sonic wave is directly related to the distance between the sensor and the water level. The travel time of ultra-sonic waves is dependent on the outside temperature and a temperature sensor could be required in order to obtain accurate results for a large range of temperatures. The sensor can be mounted from a bridge or other river crossing, or simply be mounted on a post in the river.

Advantages: The ultra-sonic sensor is located outside the stream, reducing the impact of large flows or sedimentation.

Disadvantages: The sensor could require a temperature sensor for accurate operation and is likely to have a higher power consumption than pressure sensors.

5.3.1.5 Radar Water Level Sensor

A Radar Water Level Sensor can measure the water level without being in physical contact with the water. The sensor works similar to the ultra-sonic water level sensor by measuring the time it takes for a transmitted radar wave to return to the sensor. The sensor can be mounted from a bridge or other river crossing, or simply be mounted on a post in the river.

Advantages: The radar sensor is located outside the stream, reducing the impact of large flows or sedimentation.

Disadvantages: The sensor is likely to have a higher power consumption than pressure sensors.

5.3.1.6 Acoustic Flow Meters

As opposed to water level sensor, the acoustic flow meter measures the velocity and the depth of the water in order to provide the discharge in a stream. These sensors use Doppler sonar for depth and velocity measurement and install under the water surface.

Advantages: The sensors measure water velocity and water level for instant discharge observations without calibration.

Disadvantages: The acoustic flow meters are relatively new and experience with them is limited. They are installed within the stream, making the susceptible to disturbances in the flow and sedimentation, as well as loss during high flow events.

5.3.2 Precipitation Measurement

Precipitation measurement can be divided into two classifications: intensity and amount. Precipitation intensity is the amount of rainfall that occurs over a specified time interval. Precipitation amount is the vertical depth of water that would accumulate at the earth's surface if all precipitation (including snow and ice) was in the form of water. Precipitation measurements are made at a point in space; point measurement data then are processed collectively to analyze and interpret precipitation over an area.

The current technologies available to measure liquid precipitation include:

- Manual rain gauges
- Collection tanks
- Tipping buckets
- Digital rain gauges
- Optical rain gauges
- Radar

A second division of precipitation sensors can measure precipitation in the frozen or mixed liquid-solid state. Snow sensors include snow pillows and ultrasonic devices; devices to measure snowfall include weighing gauges and reservoir gauges that contain antifreeze. It is assumed that the flood forecasting data collection network in both Ethiopia and Sudan will not require the measurement of snow depth.

5.3.2.1 Manual Rain Gauges

Manual rain gauges consist of a plastic or glass graduated measuring cylinder that is read by a volunteer observer who then reports the rainfall amounts over the telephone or radio. Accumulations of precipitation usually are made on a daily time interval. Because manual measurements are not made on an instantaneous basis, these devices do not meet the requirements for continuous, automated recording as required for a flood forecasting network. The accuracy of readings is highly variable. When not located on private property, these gauges are highly susceptible to theft.

The United States National Weather Service (NWS) has established manual rain gauge specifications for its weather observers. The gauge should have a total capacity of 51 cm (centimeters) of rainfall.

The gauge should consist of a small receiving cylinder connected to a 20.3-cm diameter funnel inside a 20.3-cm diameter outer cylinder. Rain falling into the funnel would be delivered to the receiving cylinder at a 10 to 1 ratio. A total rain accumulation of 1 cm would deliver 10 cm of water to the receiving cylinder. A measuring stick should be used to measure the rain inside the receiving cylinder.

Advantages: Manual rain gauges are the simplest and least expensive method to measure precipitation. They have the advantages of mechanical simplicity, ease of repair or replacement, and ease of measurement. In many countries, numerous volunteers are available to make observations, which can increase the spatial resolution of the network.

Disadvantages: Manual rain gauges do not provide the continuous, automated recording capability required for a flood forecasting network. They do not allow for precise measurements of the timing and intensity of rainfall at an interval less than the frequency with which the attendant visits the site. If substantial amounts of rain fall between visits, gauges without sufficient capacity will overflow and thus significantly misrepresent rainfall conditions. Evaporation losses between measurements will decrease the amount of rainfall recorded. Because of these limitations, consistent and conscientious attention is required on the part of the station attendant, particularly during inclement weather.

5.3.2.2 Collection Tank

A collection tank can be used to measure the incremental rise of water associated with precipitation events. A small structure is built that houses a tank connected to a funnel on the roof of the structure. Rain is collected through the funnel, which has an orifice of 30 cm. A shaft encoder or staff gauge typically is used to measure the height of water within the tank.

A shaft encoder uses a tape with an attached float on one end and a counter weight on the other. The tape passes over a pulley of precise circumference that rotates as the float rises and falls. The shaft encoder measures the radial motion of the pulley, typically dividing it into 100 increments. The system is calibrated so that an incremental rise in the tank corresponds with an accumulation of precipitation. Shaft encoders can be either digital or manual. The water level from a digital shaft encoder can be recorded using a data logger.

Advantages: A collection tank is relatively immune to disturbance because everything is locked within the structure, which can be built as strong as required. The shaft encoder or staff gauge is inexpensive.

Disadvantages: A collection tank cannot empty itself automatically. This means that the tank must be large enough to accumulate the precipitation that may occur over a several-day period. At higher elevations (colder) in the Ethiopian highlands, a collection tank could also require a heating element to prevent the water inside the tank from freezing and damaging the shaft encoder or staff gauge. Foreign objects or animals may interfere with the collection orifice or other parts of the system. Although the shaft encoder or staff gauge is inexpensive, it can be costly to build a structure at each gauging location. Also, continual maintenance is required to ensure that the roof does not leak where the funnel enters the structure.

5.3.2.3 Tipping Bucket

Tipping bucket rain gauges (***Figure 5-3***) are probably the most common of all precipitation measuring devices. Rain is collected through a cylindrical orifice containing an internal funnel at a height of approximately 3 m (meters) above the ground surface. In some flood warning networks of the United States, tipping bucket rain gauges employ a 30.5-cm diameter orifice; however, other diameter orifices are also available. Positioned below the collection funnel is a container divided into two compartments (or buckets) that are balanced in unstable equilibrium about a horizontal axis. Rain is transferred from the collection funnel into the uppermost bucket. The bucket will tip with the accumulation of typically 0.25, 1 or 2 mm (millimeter) of rain. When the first bucket tips, the second bucket becomes available to receive rain. The tipping of the collection bucket triggers an event switch that transmits a signal to a microprocessor contained on a data collection platform. A microprocessor keeps track of the accumulated precipitation for the corresponding time interval.

Advantages: Tipping buckets are reliable, providing good rainfall resolution (1 mm) and reasonable accuracy (+- 3 percent at a rainfall rate of 2.5 cm per hour). They are also relatively easy to maintain.

Disadvantages: The accuracy of tipping buckets decreases at high rainfall rates (15 to 25 cm per hour). During heavy rainfall, rain accumulation is not accounted for accurately during the short time that the bucket takes to tip. Also, during very light rains, it is difficult to determine the beginning and ending time of rainfall. This is because at least 1 mm of rain must fall before the bucket tips. Because of its mechanical configuration, repair costs and maintenance requirements can be substantially higher than those of manual rain gauges, although these costs can be minimized with regular maintenance inspections.

Figure 5-3: Tipping Bucket (WaterLOG YSI incorporated, used by permission)

5.3.2.4 Digital Rain Gauge

The digital rain gauge is not used widely in the United States because of its proprietary nature. The gauge consists of an aerodynamic collection funnel with a 30.5-cm diameter orifice. The collection funnel is designed to reduce collection losses caused by wind effects. The funnel passes water to a center-mounted collector tube with an internal float that measures the level of water in the tube. The water level sensor employs a digital microprocessor (hence the name digital rain gauge). As rain fills the collection tube, the microprocessor measures the time corresponding to each increment of water rise. When the tube is full, it rotates a complete 360 degrees, emptying the water and repositioning the tube for additional collection. It takes 15 seconds to rotate the tube. The microprocessor averages the rainfall rate just prior to and just after the rotation, then multiplies this average rainfall rate by 15 seconds to determine the amount of rain that would have been collected during the rotation.

Advantages: Digital rain gauges provide good rainfall resolution (1 mm), good accuracy (+- 1 percent at any rainfall rate up to 25 cm per hour), and good recording capability; also they are easy to maintain.

Disadvantages: Digital rain gauges have not been in use as long as tipping buckets and therefore experience in their application is limited. They are mechanically more sophisticated than other rainfall measuring devices, and higher costs typically are associated with these instruments.

5.3.2.5 Optical Rain Gauge

Optical rain gauges monitor the irregularities produced in an infrared beam as raindrops pass through it. These irregularities are called scintillation. A calibration is required to convert the scintillation patterns to the rate of precipitation.

Advantages: Optical rain gauges are non-mechanical. There are no buckets, siphons, or collectors to corrode and clog.

Disadvantages: Optical rain gauges require a calibration to convert the scintillation pattern into a rainfall rate. Optical rain gauge technology is relatively new, and experience with its use and maintenance is limited. Optical rain gauges measure the rate of rainfall and require an integration of this parameter over time to determine the accumulation of precipitation

5.3.2.6 Radar

Significant advances have been made over the past 10 years in the use of radar for precipitation measurement. Currently, radar can determine the location and movement of precipitation as well as estimate rainfall rates. Radar emits a band of energy at a certain frequency and employs a receiver to collect the energy reflected back from any precipitation occurring within the range of the radar. The radar receiver is equipped with a calibrated relationship called the Z-R relationship, which is used to convert the reflected energy into an estimate of rainfall.

A second type of radar is being developed that employs a two-phase, or bi-polar, radar beam. This radar modulates the polarization of the emitted radar beam and then observes the reflected energy for each of the two polarizations.

Advantages: Radar provides useful information regarding the general location of heaviest precipitation, the movement of this precipitation, and the rate of rainfall.

Disadvantages: The accuracy of radar determination of rainfall is variable. This is primarily because of the many different forms of precipitation (rain, hail, snow) that can occur and how the radar interprets them. The bi-polar radar has shown an increased accuracy in the estimation of rainfall because it can better predict the form of precipitation. The Z-R relationship mentioned previously is highly significant to the interpretation of radar data. Calibrating the Z-R relationship for storms having significantly different altitudes is a subject of ongoing research.

5.3.2.7 Rain Gauge Comparisons

A general comparative analysis is provided in ***Table 5-1***.

Table 5-1: General Comparative Analysis of Point Precipitation Measurement Technologies

	Manual Rain Gauge	Collection Tank	Tipping Bucket	Optical Rain Gauge	Digital Rain Gauge
Installation Cost	low	med - high	med	med	Med
Overhead and Materials Cost	low	med	med	med	Med
Resolution	1 mm	1 mm	1 mm	---	1 mm
Accuracy	highly variable	1percent up to 250 mm/hour	3percent up to 100 mm/hour	5 percent up to 500 mm/hour	1percent up to 250 mm/hour
Maintenance	low	med	med	med	Med
Measurement Parameters	accumulation and rate	accumulation and rate	accumulation and rate	rate	accumulation and rate

5.3.3 Additional Sensors

The flood forecasting system will mainly rely on the data obtained from the flow and precipitation gauges. In addition to these minimum requirements, it could be advisable to obtain additional information by installing extra sensors at the remote stations. The primary benefits of these additional sensors for flood forecasting are through their application as inputs to numerical weather models and a resulting precipitation forecast. They may also help justify the sharing of costs between meteorological and hydrologic agencies that are seeking additional automated real-time stations for the respective parameters of interest to them. This section provides a short overview of the sensors that are commonly available and could be considered.

5.3.3.1 Temperature Sensors

Two types of temperature sensors are commonly available, the thermistor and the thermocouple. Thermistors are solid state electronic instruments that measure resistivity across a semiconductor (usually silicon, germanium, or carbon). They normally are presented in small cylindrical configurations. Changes in resistivity across the semiconductor are negatively associated with changes in temperature.

Thermocouples are temperature transducers that consist of two dissimilar metals welded together to form a junction. When heated, the junction will generate a voltage that is converted by an equation to a temperature measurement.

Thermocouples may have fewer connection requirements than thermistors, but an individual thermocouple may have a smaller temperature range over which it operates.

5.3.3.2 Wind Sensors

Several wind direction and wind speed sensors are available. The two most applicable for the network being contemplated are the anemometer with vanes and ultrasonic (solid state) sensors.

Anemometers consist of rotating cups or an impellor mounted by a shaft to a tachometer counting system. As the force of the wind moves the cups or impellor, the counter senses and records the rotations. The number of revolutions is proportional to wind speed. Anemometers may be connected to a wind vane in a single-housed unit, or the two instruments may be mounted adjacent to each other on separate support arms. Wind direction is sensed by the rotation of a vane about a vertical shaft. Typically a transducer assembly with an established reference voltage is employed to monitor the wind direction. Voltage signals are recorded, and departures from the reference voltage are transformed mathematically to indicate direction.

Ultrasonic sensors are solid state devices that measure wind speed (and usually direction) by sensing the differences between sound wave travel times in moving air between several probes. Measurements may be made in both directions between probes. As the air speed over the probes varies, upwind ultrasound travel times increase, and downwind travel times decrease. For zero wind speeds, the forward and reverse travel times are the same. A micro-controller computes wind speed along the path, independent of altitude, temperature, and humidity.

Anemometers have been used for a considerable amount of time and are readily available from a number of competing manufacturers, with a wide variety in accuracy and precision, as well as in operating conditions. Anemometers and vanes contain moving parts that are susceptible to wear, tear, and corrosion. Ultrasonic wind sensing is still a fairly new technology, resulting in a higher upfront cost as compared to the Anemometer and vane combination.

5.3.3.3 Relative Humidity Sensor

Electronic relative humidity sensors are solid state instruments that typically are based on the capacitance change of a thin film capacitor. A thin dielectric film absorbs water molecules through a metal electrode, causing a capacitance change that is proportional to relative humidity. Responses to humidity changes are typically fast and generally linear with small hysteresis. Some capacitance-based sensors have negligible effects from temperature changes. Others that may be sensitive to temperature variation can be combined with a temperature sensor. The resulting measurements can then be compensated for temperature changes. Frequently, a relative humidity sensor and a temperature sensor are configured as one unit.

Electronic relative humidity sensors must be shielded from solar radiation and precipitation. Typically, some form of ventilated plastic shield is used for such purposes, and this usually is incorporated into the design of the unit. Electronic relative humidity sensors are subject to errors from airborne contaminants coming into contact with the capacitor.

5.3.3.4 Solar Radiation Sensor

The most extensively-used sensor for global solar radiation is the pyranometer. Pyranometers are sensors that use a silicon photovoltaic cell, a thermocouple, or a thermopile to measure incident solar radiation. The thermocouple- and thermopile-based sensors use a clear glass dome to house the mechanism. The WMO rates the thermocouple or thermopile sensors into first-class and second-class, depending on factors including sensitivity, accuracy, and temperature dependence. The first-class sensors are sensitive to a wider range of solar irradiation, have more linear responses, and are more accurate under the range of operating temperatures. Silicon photocell sensors are less expensive than the WMO first-class or second-class interments, but have more limited measurement accuracy and usually do not sense the longer wavelengths measured by the WMO-class instruments. Under favorable conditions of clear, unobstructed daylight, a silicon photocell sensor may yield results within 5 percent of its more expensive counterparts. This may be adequate for certain data collection objectives.

Pyranometer measurements can be in error if dust or other obstructions settle on the silicon cell or the glass housing. Installation guidelines, particularly regarding leveling and radiation obstruction or reflectance, should be followed. These may limit site selection or station configurations. Periodic inspection, maintenance, and calibration checks are necessary.

5.3.3.5 Soil Moisture Sensor

The following review of soil moisture measurement does not include gravimetric or airborne methods. Both of these approaches are significantly less suitable for a real-time flood forecasting data collection network than the sensors described below. While reliable, the gravimetric method is a labor-intensive, destructive sampling approach that does not yield automated, continuous data. It should be used, however, as a baseline method to assist in the calibration and quality assurance of the sensor installations described. Airborne techniques, such as those using gamma ray sensors or microwave radiometers, are still in a relatively experimental stage of development and require expensive equipment and ground-truthing.

Resistance blocks are typically sets of gypsum blocks that are buried in the soil at specific intervals. When placed in direct contact with the soil, the gypsum blocks are assumed to absorb soil moisture and come to an equilibrium moisture state with the surrounding soil medium. The resistance of a given block to an electric current is related to the water it absorbs, increasing with decreasing water content. By calibrating the resistance readings with gravimetric moisture analyses, the readings can give an approximation of the soil moisture.

Enclosed Granular Matrix Sensors operate on much the same principle as the resistance blocks described previously. Within a perforated cylindrical case made of stainless steel or other corrosion-resistant material, electrodes are embedded in a sand-like reference matrix. The matrix absorbs water from the soil medium, and changes in electrical resistance are recorded.

Both methods of soil moisture measuring will deteriorate from exposure to the soil and will need to be replaced at regular intervals.

5.4 Meteorological Site Location

As noted previously the core of a typical hydrologic forecasting system is the potential to predict the runoff response of a basin to precipitation. Measurement of precipitation throughout a river basin is therefore fundamental to the development of forecasts.

5.4.1 Station Density

The total number of rainfall gauges employed in a gauging network has a direct effect on the network's ability to represent the spatial distribution of rainfall — the more rain gauges employed, the less likely that a rain event will pass through the area undetected or inaccurately represented.

The National Weather Service (NWS) has developed a guideline to determine the minimum rain gauge density necessary to detect and quantify flood-causing precipitation. The guideline is based on a minimum gauge to catchment area relationship of $N = A^{0.33}$, where N is the number of gauges and A is the area in square miles.

The WMO has developed a guideline (WMO 1994) to determine the minimum rain gauge density for water resource applications (not specifically flood warning). The minimum rain gauge density will prevent serious deficiencies in detecting precipitation elements. The WMO defines seven distinct physiographic zones: (1) coastal zones, (2) mountainous zones, (3) interior plains, (4) Hilly/undulating zones, (5) small islands, (6) urban areas, and (7) arid and polar zones.

Zones 2 and 3 best describe the physiographic regions of the flood prone areas in Ethiopia. *Zone 7* includes the areas of the world were it is unlikely that acceptable densities can be obtained due to sparse population and the lack of communication possibilities. Although the northern part of Sudan can be described as arid, it does not fit the description of *Zone 7*, and therefore *Zone 3* seems more appropriate.

The WMO defines the minimum density of recording precipitation gauges for *Zone 2* to be 2,500 square kilometers per station. For Zone 3, the WMO defines the minimum density of recording precipitation gauges to be 5,750 square kilometers per station

Table 5-2: Guidelines for Recording Precipitation Gauge Densities

Country	Area (million km^2)	Area in Project Area (million km^2)	WMO recommended rain gauges	NWS recommended rain gauges
Ethiopia	1.13	0.36	63-144	50
Sudan	2.50	1.00	174	70

The WMO guidelines include precipitation gauges for water resources management beyond the scope of flood forecasting. In Sudan the data collection network is limited to the prediction of riverine flooding, excluding data collection for local or flash flood events, which makes it likely that reliable riverine flood forecasts can be developed based on less gauges than recommended by the NWS. In addition to the guidelines, more detailed information regarding local topography, meteorology, land use, and other physical aspects of the project area will need to be considered in determining the gauge density.

The measurement of environmental parameters such as temperature, relative humidity, solar radiation, wind speed, and wind direction typically requires a gauging network that is much less dense than that required to measure and quantify precipitation. This in part is because the spatial variation of atmospheric parameters (such as temperature) is less than that of precipitation.

Both the NWS and the WMO simply recommend that the minimum density for expanded meteorological stations can be less than that required for precipitation gauges, and that the density chosen must adequately describe the climate of the area both quantitatively and qualitatively. Examples of network designs have been published by WMO for some developing countries. These examples strongly demonstrate that the data collection objectives influence selection of climate station locations and density. The data collection objective for this project is to collect the data required for flood forecasting. However, it is advisable to design the network in a way that does allow for future shift in the objective of the data collection network and allow for additional sensors to be installed at the meteorological stations.

5.4.2 Station Siting and Exposure

Data collection sites should be located in an open setting that is representative of the locale. They should not be located at the sides of buildings; near trees; or otherwise sheltered from wind, rain or sun. Caution should be exercised to ensure that the ground surface on which the station is located represents the desired monitoring conditions and objectives. For example, installing a station on a parking lot surrounded by buildings may be appropriate for monitoring street-level conditions in an urban area, but would not be representative of the rural conditions surrounding the town or city.

Rain gauges should be positioned away from any nearby obstruction at a horizontal distance of at least four times the height of the obstruction (WMO, 1994). For example, if the station is near a tree that is 15 m high, the gauge should be at least 60 m from the tree. The gauge orifice must be in a horizontal plane, open to the sky, and above the level of droplets splashing from the ground. Most tipping bucket rain gauges have adequate wind protection in the form of a shallow brim around the orifice.

In addition to the siting requirements for the rain gauges, the location of the station should take requirements for other sensors into account in order to simplify the possible expansion of the parameters collected by the data collection network. The following requirements could be considered for location a meteorological site:

- Temperature and relative humidity sensors typically should be at least 30 m from large paved surfaces and located in an open level area at least 9 m in diameter. The site should have a ground cover (vegetation, crop, or natural earth) representative of the local area being monitored.
- Wind sensors should be located in open terrain and should be positioned away from any nearby obstruction at a horizontal distance of at least ten times the height of the obstruction. For example, if the station is near a house that is 5 m high, the station should be at least 50 m from the house.
- Pyranometers should be positioned away from buildings and trees, and must be located such that shadows or reflections do not fall on the sensor. Mounting the sensor at the end of a cross arm will minimize shading from other instruments at the station.

5.4.3 Accessibility

In order to maintain the network, all proposed stations will need to be easily accessible throughout the year.

5.4.4 Security

Perimeter enclosures for meteorological stations are typically made from 2 m high steel chain link fencing that may be topped off with two or three strands of barbed wire. Steel posts set in concrete form the corners and interim supports. A lockable chain link gate, possibly wide enough to drive a vehicle through, is essential. If the gate is comprised of two sections, they should be strongly supported and vertically pinned into concrete at the center. At some installations, it may be necessary to place light woven wire netting over much of the perimeter enclosure to keep large animals and birds away from the instrumentation. Fencing and netting should be configured so that it does not cast shadows on outside sensors.

5.4.5 Existing Site Locations

The preferred location for the proposed meteorological stations will be at sites that are currently used for weather observation. Not only will this provide a certain level of infrastructure that is already available for the proposed station, it will also extend the period of record for the proposed station, which can be beneficial in future climatologic research.

5.4.6 At Hydrometric Sites

In order to cost effectively expand the meteorological network, rain gauges will be added to all proposed hydrometric stations.

5.5 Hydrometric Site Location

5.5.1 Station Density

In order to verify simulated hydrographs at forecast points and increase confidence in simulated/routed hydrographs at downstream forecast points, observations of stage and calculations of discharge are required at hydrometric gauges.

The World Meteorological Organization (WMO) defined the minimum density of recording stream flow gauges for *Zone 2* to be 1,000 square kilometers per station. For Zone 3, the WMO defines the minimum density of recording precipitation gauges to be 1,875 square kilometers per station. The guideline for stream flow gauges does not distinguish between recording and non-recording gauges.

Table 5-3: Guidelines for Stream Gauge Densities

Country	Area (million km^2)	Area within Project Location (million km^2)	WMO recommended stream gauges
Ethiopia	1.13	0.36	192-360
Sudan	2.50	1.00	533

The WMO guidelines include stream gauges for water resources management well beyond the scope of flood forecasting. The large number of gauges recommended by the WMO will aid in determining the availability of water resources, as well as their spatial and temporal distribution. For a real time flood forecasting network however, this large number of gauges is not necessary except as required to support associated forecast points in populated areas and is considered excessive for the present forecasting needs of Ethiopia and Sudan.

5.5.2 Hydraulic Conditions

In order to have accurate flow data for a large range of flows, the suitability of a site can be assessed by the following hydraulic criteria:

- The general course of the stream is straight for about 100 meters upstream and downstream of the gauge site.
- The total flow during all flow conditions and river stages are confined to a single channel.
- The riverbed and riverbanks at the gauging site have to be stable without excessive sedimentation and scour over time.
- The riverbanks need to be clear of vegetation and the river should be free of aquatic growth.
- There should be a stable relationship between water stage and flow at all water levels. In order to calibrate and verify the relationship, a location where discharge can be measured should be located at or reasonably near the stream gauge.
- The gauge should be located far enough upstream of a confluence to avoid influences from the other stream.

In addition to the hydraulic criteria, the gauges need to be accessible, being able to connect to the telemetry system, as well as provide a location for the stage recorder and other equipment. In practice it is rarely possible to identify sites that satisfy all of the criteria identified above and also meet requirements for hydrologic sub-division and warning locations. It is therefore necessary to balance all the requirements in order to establish a network that provides accurate stream flow information at needed locations.

5.5.3 Accessibility

In order to maintain the network, all proposed stations will need to be easily accessible throughout the year.

5.5.4 Security

The hydrometric station needs to be protected against vandalism and theft, as well as high water levels in the river. In order to protect the station against high water levels, the station needs to be located on the banks, well above the highest expected water level.

Perimeter enclosures for hydrometric stations are typically made from 2 m high steel chain link fencing that may be topped off with two or three strands of barbed wire. Steel posts set in concrete form the corners and interim supports. A lockable chain link gate, possibly wide enough to drive a vehicle through, is essential. If the gate is comprised of two sections, they should be strongly supported and vertically pinned into concrete at the center. If additional meteorological sensors are installed at the hydrometric station additional measures could be required to keep large animals and birds away from the instrumentation. These additional measures are described in the section on meteorological stations.

5.5.5 Existing Site Locations

If, after thorough review, the existing stream gage locations are determined to meet the hydraulic requirements outlined in this chapter, the proposed hydrometric stations will be located at existing stream gauge locations. This will allow the observed flows to be combined with the historic record of the existing station, extending the period of record which will be valuable for calibration and water resources evaluation. In addition, the historic record will aid in defining the highest expected water level. Using existing sites also permits using much of the existing infrastructure already in place, including operators, security and year round accessibility of the site.

5.6 Telemetry System

Communications systems considered for the Flood Forecasting data collection system should use technology that is mature, reliable, and available in Ethiopia, Sudan and Egypt and throughout most of the world. To be considered, the communications system must be used commonly for collecting environmental data, and the required hardware must be commercially available.

5.6.1 Manual data transmission

One option for network telemetry is the manual transmission of data by an observer using whatever technological means are available, including some of the options for automated transmissions discussed in the following paragraphs. This option is noted separately here because it has distinct characteristics, advantages, and disadvantages. For existing conventional sites no additional observation equipment is required, initial costs for network implementation are minimized, and network maintenance costs are also low. Little additional training of staff is required to operate this type of network. Primary disadvantages are that they require significant labor to operate on a daily basis, measuring and reporting frequencies are limited to several times per day at a maximum, consistency of measuring and reporting is variable, depending on human factors, and accuracy is difficult to verify.

5.6.2 Common-carrier Telephone

Where a common-carrier telephone infrastructure is available, it may be used for fairly reliable and cost-effective direct-dial communications by modem between field installations and receiving stations. Various systems may offer either scheduled or unscheduled polling of stations for data as well as alarm reporting (when data readings increase at a pre-defined rate or cross a threshold value). Baud rates typically range from 300 to 9600. Speech modems also are available; these use a formal spoken (recorded) vocabulary to transmit data to the receiving station. It should be noted that common-carrier telephone networks are typically dynamic, ever-changing systems. They may use several types of technology at any one time, and regional managers often have different sets of operating priorities. Successful data collection requires close working relationships and constant interaction between the data network operators and the telephone organization(s).

The primary disadvantage of the common-carrier telephone system is the lack of facilities throughout the Eastern Nile countries (particularly in rural areas). Also, depending on the time step for data transmittal, a large number of calls and associated telephone lines may be required, and this may result in substantial ongoing expenses.

5.6.3 Low Frequency (LF) Radio

Many countries (including Sudan) use long wave radio to communicate by voice with staff at remote sites to receive manual data observation reports. Long wave radios operate on the low frequency band with a frequency between 30 and 300 kHz. The reason for using the low frequency band is that the wave signals bend with the curvature of the earth, allowing for communications over large distances without the requirement for repeater stations.

Although many countries have a positive experience with the low frequency radio system for voice communications, transmitting data packets over the same frequency is not likely to be easily implemented or sustainable..

The quality of the signal reduces with the distance between the transmitter and the receiver. With analog transmissions, like voice, a reduction in signal quality is normally not a major concern. When transmitting digital packets however, signal quality is important for successful transmission of the data. In addition, in order to transmit the signal over long distances, relatively high transmitting power is required. This is likely to result in interference near the transmitter. In an ever increasing use of the available radio spectrum, this problem will increase with time in developing areas.

Due to the drawbacks of the low frequency band for data transmission, the low frequency band is mainly used for navigation, time signals, certain radio broadcasts and amateur radio. As a result, the required equipment to send data packets on the low frequency band is not readily available from major communication equipment manufacturers.

5.6.4 Wireless Telephone (GPRS)

General Packet Radio Service (GPRS) is a protocol that allows for transmission of data on the Global System for Mobile Communication (GSM). This service may be useful in remote areas where a telephone line infrastructure does not exist. Obviously, cellular service must be available, and the GPRS protocol must be supported in order to implement this technology.

Cellular telecommunication avoids the need for costly installation and maintenance of a separate telemetry system. Cellular communications within an existing cellular network are relatively easy to set up and require minimal design. A third party is responsible for maintenance of the overall communication network. During periods of high traffic (such as emergencies), adequate bandwidth for the data transmission may not be available at adequate time intervals.

The distance from the remote stations to the nearest GSM access tower is limited to approximately 35 kilometers, which is the result of the technical limitation of the GSM protocol.

Experience with these networks in other countries has showed that even though the GPRS protocol is supported and easily accessible by mobile phone, efforts to set up data transmission over this protocol are not always successful.

5.6.5 Line-of-sight Radio Frequency

These systems use VHF, UHF, or microwave radio frequencies to communicate between the field and base stations. Many remote stations (on the order of 200) may be connected in this type of system. The main difference between VHF, UHF and microwave radio is the frequency on which they work. VHF works with a frequency between 30 and 300 MHz, and UHF between 300 and 3000 MHz. Because attenuation of the signal is less at lower frequencies, VHF is likely to provide better performance as compared to UHF for stations that are located far apart.

Microwave radio frequency for data transmission network commonly refers to frequency ranges well above 3 GHz. At these higher frequencies significant more data can be transmitted than in the UHF and VHF bands. Disadvantages of the microwave radio frequency are the higher power requirements due to the attenuation of the signal and that the required equipment tends to be more expensive. Common applications for a microwave radio network are as a backbone system connecting several UHF or VHF systems to a single base station.

Typically, a radio-frequency modem and a transceiver are installed at the field station, and repeaters connect the radio signal to a transceiver at the base station. (Repeaters are specialized stations that are used to extend the range of a DCP or to avoid topographic barriers.) Depending on the network configuration and selected components, data collection stations may be provided with repeater hardware.

Successful line-of-sight radio frequency communication networks require extensive, careful planning and field testing. Because the transmitter must be within the line of sight of the receiver, the approximate range is about 65 km (kilometer) (where there are no topographic obstacles) and is determined by the curvature of the Earth. In addition to the sensor network design, a radio path study is required to ensure viable communication between each DCP and the base station. The radio path study usually is conducted in two stages. The first stage uses topographic maps or a digital elevation model to determine the communication paths, communication distances, and probable repeater locations. The second stage is a field study in which radio equipment (of the type and frequency to be used in the actual network) is used to verify that the radio path are viable. The radio path study required for successful network implementation *is a significant upfront cost that must be considered*.

Line-of-sight radio transceiver systems allow for frequent data collection from a large number of stations, which is highly desirable where weather phenomena or floods threaten lives and infrastructure. Radio systems are less susceptible than line-based telephone networks to physical interruption.

Disadvantages of the line of sight radio are that it is difficult, especially in mountainous or densely-vegetated areas to provide a line of sight between the transmitter and the receiver. Where the network covers a large geographic area, the numbers of repeaters required to transmit the data to the base station could exceed the number of remote stations used in the systems. In a very dense network, adequately equipped stations can maintain data transfer if a repeater malfunctions. Based on the preliminary findings however, it is unlikely that the data collection network used for flood forecasting will be dense enough to provide this functionality. This would result in loss of data transfer from several stations if a single repeater fails.

In spite of these disadvantages, line-of-sight radio components may be used to complement other telecommunications systems, such as to relay data from a meteor burst master (discussed below) station to a data collection center. Other common uses of line of sight radio in a network that is based primarily on another type of telemetry are as follows:

- A station located in a deep gorge may not be within the range of GSM coverage, may be blocked from a direct view of a satellite, or may not be within the line of sight of a reflected meteor burst signal. A repeater can be located strategically at the top of the gorge within line of sight of the station. VHF radio can be used to transmit from the station to the repeater which will then be within reach one of the other telecommunications signals.
- A station located in a remote area without GSM coverage can be linked via VHF radio to another station that does have GSM coverage. Data from both stations are then broadcast through the GSM network.
- Water level within a reservoir as well as tailwater elevation downstream of a reservoir are needed. Instead of installing two complete stations, a radio signal is used to communicate water level from a station below the reservoir to the gauge at the dam, which then transmits data from both stations through a satellite or meteor burst system.

5.6.6 Meteor Burst

Meteor burst communications are based on the reflection of transmitted radio waves off of ionized meteor trails in the Earth's upper atmosphere. Billions of small meteors (on the order of 1 mm (millimeter) in diameter) enter the ionosphere each day and provide a fairly reliable mechanism for data transmission. As with other data network configurations, meteor burst systems operate through a set of remote stations transmitting to a master station. A probe signal (transmitted by the master station to a remote station) determines the existence of a usable meteor trail. When the remote station receives a signal, the remote station acknowledges it and transmissions begin. This handshaking arrangement consumes some portion of the ionized trail's usable life and places a limitation on the rate of data transmission. Typical transmission rates vary from a few kilobits per second to over 100 kilobits per second. The systems typically transmit in the 40 to 50 MHz frequency range.

To be useful, meteors must produce an ionized trail with an acceptable reflection loss, which requires the meteors to be larger than about 1 mm in diameter (depending on their mass). Larger meteors are more desirable but much less abundant than needed for system reliability. The meteors also must occur within a common volume of the ionosphere that is (1) within the line of sight of both the remote station and the master station and (2) at an altitude of generally 80 to 120 km. Lastly, because transmittals occur through reflection, the meteor paths must be essentially tangent to the surface of an ellipse of which the two stations are the foci. The presence of usable meteors varies diurnally and seasonally according to solar influences on the ionosphere. The systems can be very sensitive to electromagnetic noise, which largely restricts their use to remote regions that are away from cities, highways, and power lines.

A typical Meteor Burst Communications System will consist of at least one Master Station and one or more Remote Data Collection Stations, each of which will include a packet radio (modem/receiver/transmitter) interfaced to a data logger and sensors. The Master Station must operate as the controlling station, collecting data from each Remote Station by continuously transmitting via its packet radio an interrogation (probing) signal.

Based on our findings, the base stations are likely to be located in densely populated areas with an abundance of electromagnetic noise (Addis Ababa, Khartoum). Due to the sensitivity of the Master Station to electromagnetic noise, this will not be a preferred location for the Master Station and it would be necessary to construct the Master Station in a more remote area and convey the data from the Master Station to the base station by a line of sight radio or other telemetry method.

5.6.7 Satellite Systems

In order to use a satellite system for the telemetry, access to a satellite is required. Two options are available for connecting to a satellite network. The first option is to make use of an available meteorological satellite. The Argos satellite and the METEOSAT satellite provide coverage for the Eastern Nile Basin and allow for free transmission of meteorological data. The second option is to contract with a commercial satellite network provider.

The Argos system was established by a joint agreement between NOAA (National Oceanic and Atmospheric Administration), NASA (National Aeronautics and Space Administration), and the CNES (Centre National d'Estudes Spatiales) in 1978. Argos is in a low earth orbit (between 300 and 800 km) and provides about eight transmission windows per day during which the DCPs can transmit data; this window varies somewhat. Under certain conditions, it may be possible to only transmit four times successfully each day. The Argos ground station distributes received data to potential users. Argos is responsible for the downlink hardware operation and maintenance. Data dissemination services are distributed by Argos under a user agreement where data are available over the internet. The communications with the satellite are one-way, from the field to the base station. No station polling or remote network re-configuration capabilities are available with Argos network.

The METEOSAT satellite is operated by the European Organization for the Exploration of Meteorological Satellites (EUMETSAT) and their primary goal is to collect and disseminate weather imagery. However, these satellites do also allow for low-rate data transmission through the Data Collection System (DCS). The information from the Data Collection Platform (DCP) can be transmitted to one of the Geo-stationary METEOSAT satellites in two different ways. The first method is the self-timed option which transmits a message to the satellite at fixed timeslots. These timeslots normally vary between once every one or three hours, but other intervals are possible. The second method of communication with the satellite is the alert platform, in which the DCP transmits when a threshold level for a parameter has been exceeded. The messages from the DCP to the METEOSAT are transmitted to the Main Control Center of EUMETSAT in Darmstadt, Germany, from where they are made available to the user. The communications with the satellite are one-way, from the field to the base station. No station polling or remote network re-configuration capabilities are available with a METEOSAT network.

The second option involves contracting with a commercial provided. Several providers are available that provide data communications between a ground station and the satellite. The commercial systems use a variety of satellite technologies and most will allow for two way communication, allowing for polling the remote station as well as reconfiguring the station without a site visit. Examples of commercial systems using a GEO satellite are:

- INMARSAT (Geo stationary)
- Thuraya (Geo stationary)
- Orbcomm (Low Earth Orbit)
- Iridium (Low Earth Orbit)

Since these systems support voice communication as well as data communication, the DCP hardware is more complex than some of the other satellite systems discussed. The two-way communication capability of this system is also reflected in the higher cost of the uplink transceiver. The cost of using the system is based on how much throughput of the system is used. Data from the system are received at commercial downlink sites through the internet.

5.7 Data Transmission Protocols

This section describes how communication takes place within the telemetry network. The information is important because the telemetry protocol influences the bandwidth of the system, the reliability of data transmitted by the system, how often data can be received by the base stations, and the relative complexity of the hardware. It should be noted that the telemetry system used could limit the available data transmission protocols. For example, the METEOSAT only allows for one way communication, making it impossible to develop an interrogated system. For the purpose of this section, the field data collection equipment and its associated data logging, control, and communications equipment will be referred to as a DCP.

5.7.1 Interrogated Systems

Interrogated systems generally are configured where a base station requests information from the DCPs. Each DCP is assigned an identifier so that the DCP knows when to transmit information requested by the base station. Interrogated systems require communications in both directions, but in the simplest designs the DCPs may be very basic, transmitting the last measurement collected without processing or storing data at the DCP. The base station assigns the time to the transmission.

5.7.2 Broadcast Systems

Broadcast systems generally are configured where the DCPs transmit data with no dependency on the base stations. Because there is no dependency on the base station, communication with broadcast DCPs is in one direction, from the DCP to the base station. Because the communication is one-way, communications equipment is less expensive that the interrogated system.

5.7.3 ALERT

ALERT is a broadcast protocol that was designed by the National Weather Service (NWS) in the United States. ALERT stands for Automated Local Evaluation in Real Time. The ALERT protocol originally was designed to collect streamflow and precipitation data to help local emergency management personnel make good decisions during flooding events. Data are transmitted to the base station when precipitation or streamflow amounts exceed a threshold

5.8 Base Stations

5.8.1 Functions

The data collection base station is a location where data from the network is received, decoded, checked for quality, and stored. A base station can be as simple as a PC with an internet connection or it may be a complex system with powerful computers and communications equipment.

A base station normally performs the following functions:

Receive data - These data may be automatically received through the telemetry network with some provision for receiving data phoned in by manual observers. In order to receive the data, the base station can be equipped with an RF receiver, an internet connection, a phone line, a satellite downlink, or any combination as required by the telemetry network.

Decode data – Data transmitted by a telemetry system are generally encoded. These data need to be decoded before further processing or before they are stored in the database. The decoding of the received data may require additional specialized equipment to perform this task.

Quality check - Most base station systems implement some kind of data quality checking. This checking is not generally comprehensive and usually is intended only to flag ridiculous or obviously out of range values before they are stored or otherwise used.

Data storage - Most data collection systems store data in some sort of database so that a historical record is developed. Also, the database is useful for storing intermediate results or results derived from data collected by the network. Simple data collection networks where the volume of data is kept small can utilize a simple and inexpensive database product like MS Access. For larger networks a more powerful commercial relational database management system (RDBMS) product running on database server class machine might be required.

Data processing and dissemination - In most systems, software is necessary to manipulate or compute useful information from data collected by the network. Software is generally written to query the database and supply data to users over a local area network. Web-based database displays are also popular and allow users to access data with no other software than a web browser.

5.8.2 Equipment

The base station facility will house the monitoring network computer, spare parts and support equipment. In addition, the base station should provide space for a flood forecast computer. The base station will control network communications and operate the network management software. The principal components of the base station shall include:

- Base station radio
- Computer
- Network and data logger operation software
- Back up power supply

At a minimum, the center will require 220 VAC power, telephone, and an internet connection. The space will require a table or desk for placement of the computer and equipment, shelving for storage of spare equipment and storage for the backup storage batteries and chargers. A space of 12 to 15 square meters should be sufficient and should be in a secured place.

5.8.2.1 Base Station Radio

The base station radio will be responsible for maintaining communications with the remote radios. As such, the radio, modem, and antenna will depend on the telemetry system. At a minimum it should include the following items:

- Radio
- Radio modem
- Antenna
- Antenna Tower
- Surge Protection
- 12 VDC 100 amp hours backup battery storage
- Omni directional antenna

5.8.2.2 Computer

A computer will be required for the operation of the monitoring network. The monitoring network computer will be a standard computer with keyboard, pointing device and display. A second computer could provide system redundancy in case of problems with the first computer. The computer should meet the minimum requirements as identified by the manufacturer of the network and data logger operation software

In addition to a computer, a printer and necessary office supplies will be required for satisfactory operation of the base station.

5.8.2.3 Network and Data Logger Operation Software

Network and data logger operation software is required to support the monitoring network. The software should support automated scheduled and event based communications, as well as data logger programming and data report generation. The software should be developed or recommended by the manufacturer of the telemetry system to aid in integration of the telemetry network.

5.8.2.4 Computer Back Up Power Supply

To provide continuous operation, even during inclement weather, the base station must include a backup power supply to provide up to 120 hours of operation without external AC power. 12 volt DC power will be needed to power the radio at the base station

5.8.3 Data Processing System

Several software packages are available that can be used for data processing. Some of the packages provide comprehensive functionality, where the software package can handle all the steps from reading the data report generated by the data logger operation to data storage and dissemination. Other software packages will only provide parts of this functionality and integration of the system will need to be provided either by the software manufacturer or a third party. For a complete Data Processing System that can be used for flood forecasting, it should at least comprise the following functionality:

- Obtain observed data from the data report for all measured parameters
- If encoded data is used in the telemetry system, the DMS must decode the data
- Provide automatic error checking functionality
- Allow for manually observed input
- Develop and manage rating curves for hydrometric gate locations
- Calculate instantaneous discharge based on stage and rating curve
- Access data from outside sources
- Provide functionality for data storage
- Provide functionality for data retrieval
- Provide functionality for data archiving
- Provide statistical functionality
- Capable of triggering an alarm if threshold values are met.
- Comprehensive and flexible reporting facilities
- Provide functionality to share data with third parties (including the forecast system) through an automated process.
- Accumulate point precipitation data at multiple time intervals (15 minute, hourly, 6-hourly, daily, etc)
- Map display with access to numerical and graphical depictions of recent observations of key parameters for each station

5.9 Regional Data Sharing

The minimum requirements of a data sharing component of a regional data collection system can be met using a simple technological solution and careful coordination between parties to the data sharing agreement. One approach to such a system is simply to set up an FTP server with a defined directory structure for posting and retrieving data, and to agree upon data and file formats and file naming conventions for data to be shared. Parties to the data sharing agreement individually define automated processes to post data to the site. Postings can be defined to include data redundancy to compensate for potential power or network outages. The parties also define automated processes to query the ftp site for new or recently added data from other parties for downloading and processing. One of the parties or a third party that manages the site can define automated processes to archive or remove files after a specified number of days.

This approach permits rapid deployment of the system based on clearly agreed protocols from the individual parties to the data sharing agreement. It requires each party to configure its data processing system to post and retrieve agreed upon/desired data and to share metadata in advance so that the data posted to the site can be properly interpreted. It does not, however, lend itself well to data browsing or visualization. If the parties have a clear understanding of the desired data and have effective communication regarding the types and formats of the data, This type of system can meet data sharing requirements for extensive networks and large amounts of data of multiple data types. This could be coordinated as part of the Eastern Nile Planning Model (ENPM) administrative agreements.

An alternative approach is to establish a separate data processing system at a regional data sharing facility, including a database for data storage and interfaces for both local and remote access to data, potentially including web-based viewing. Such a system could be configured with automatic and manual data entry interfaces to permit ingest of remote data into the system. Likewise, automatic and manual interfaces could be defined for download of desired data. The system would resemble the data processing systems of the individual parties to the regional data sharing agreement. The purpose of a system of this nature would be that it permits the organization that is promoting and hosting the regional data sharing function to more fully participate in review, assessment, and use of the available data and to be more proactive in coordinating with each party to the agreement regarding station definitions and data types.

Even with a regional data processing system, the most effective approach for automated data exchange between parties may be through an FTP sever at the regional facility. This could allow a staged approach to deployment, with the FTP server being established initially based on the developing data processing capabilities of each party and a complete regional data processing system implemented subsequently or concurrently.

One example of a common data format that can be used for data sharing is the Standard Hydrologic Exchange Format (SHEF). This format is generally readable for a human reviewer to verify system functioning. It includes flexibility to report a single data value for a given station, multiple data types for a given station, or time-series of data for a given station. It permits identification and exchange of observed or forecast data as well as posting of corrected or updated values to replace previously reported values. Many data processing systems are able to generate or decode SHEF data reports. It supports an extensive set of hydrometric and meteorological parameters and multiple time intervals. Use of a format such as this can permit individual parties to a data sharing agreement to operate independent data processing systems while conforming to a data exchange format that imposes a common set of standards on data definition and exchange.

6. Recommendations

The recommendations outlined below consider the development of national and regional systems for data collection, telemetry, data processing, and data communication and sharing. They begin with the presentation of an implementation strategy that identifies a sequence that encourages institutional development consistent with the introduction of new technologies and the growth of the network. Following the implementation strategy are recommendations for the development of the institutional setting for the forecast and data collection systems. This discussion is applicable to both Sudan and Ethiopia, and has valuable information that could be adapted to the circumstances in both Egypt and at ENTRO. Following these general recommendations are specific recommendations for the data collection network, the telemetry system, a data processing system, and regional data sharing. The specific recommendations are presented separately for each country, with a section also for ENTRO. A complete implementation and procurement plan, together with technical specifications and sample Terms of Reference, are developed as separate documents.

6.1 General Implementation Strategy

The recommended network implementation strategy is based on three interrelated principles, that are crucial to ensure the successful completion of the planned upgrades. These principles are:

6.1.1 Stakeholder Involvement

Riverside’s experience is that only full stakeholder involvement can create the stakeholder ‘ownership’ required to ensure the continued operation of any system deployed with outside help.

Ownership is best built through continued and extensive involvement of the national Ministries and ENTRO in all planning, procurement, installation, training, operation, and support activities that are part of implementing the envisioned data acquisition, data processing, and communication systems to support flood forecasting.

Providing a full understanding as to the required level of effort is a first and crucial step in ensuring the Ministries and ENTRO involvement. This can be achieved through a Study Tour and planning meetings at the beginning of the project phases and continued assessment meetings as part of the Adaptive Management principle (outline below).

With this in mind, Riverside recommends that Ministries and ENTRO staff participate as much as feasible in all activities and manage as many sub-tasks as possible, supported by continued training and outside consultants when necessary.

6.1.2 Adaptive Management

Adaptive management is a process that utilizes continuing *Implementation – Assessment – Adjustment* cycles throughout the project. These cycles ensure that at any major point during the project the effectiveness of the measures implemented to date are critically evaluated with respect to the project goals. If a certain measure (e.g., an initially chosen telemetry system) does not lead to the expected results (e.g., reliable data transmissions) then corrective measures can be decided upon and employed (e.g., the use of another telemetry system). This adjustment or adaptation ensures that unfeasible implementation pieces are identified early on when the investment is still small and corrective actions can easily be undertaken. Ultimately this will lead to a more robust and successful outcome. Therefore, regular assessment meetings are recommended throughout all project phases, with the expectation that adjustments to some system pieces will likely be necessary.

6.1.3 Phasing

Experience suggests that countries are rarely successful in establishing an extensive hydrometric and meteorological network of automated real-time reporting stations in a single effort. Such projects often contemplate a significant investment in equipment, software, installation, and training, yet the organization does not posses the capacity to operate and maintain the network and all of its components, or even for a limited number of staff to comprehend the training in a variety of new technologies including sensor maintenance, data logger programming, remote power system maintenance, telemetry, base station configuration and operation, and many aspects of data processing. Lacking an understanding of troubleshooting or maintenance priorities, the complex system becomes overwhelming and may fail entirely. When new technologies are adopted with a careful, measured approach, capacity and understanding can grow with the system and a sustainable development can take place. When implemented over time, designs that are overly ambitious can be scaled back to be consistent with institutional capacity as that capacity is reached.

Riverside therefore recommends a phased approach in implementing the upgraded data acquisition, communication and flood forecasting systems. This allows the national Ministries and ENTRO to expand their capacities consistent with the growth of the upgraded systems, thus avoiding implementing systems that cannot be sustained. In addition, it allows for logical break points at which the concluded activities can be critically evaluated as part of the Adaptive Management strategy outlined above. Phasing will also allow the national hydrometeorological networks to implement the highest priority climate and stream gauging sites first, allowing the involved Ministries to gain experience at these crucial locations as early as possible and to apply the lessons learned in later phases. Based on these principles, Riverside recommends the upgrade of the data acquisition, communication and flood forecasting systems be performed in four main phases:

1. **Technology Selection** – Although Riverside can make recommendations regarding many of the technologies to be applied for overall data collection and processing, each country and institution needs to be confident that the selected technologies can be implemented successfully prior to major investment. This phase has two main components.

- The first is a study tour for stakeholders to observe first hand various technologies for sensors, telecommunications, and data processing.
- The second component is the establishment of a demonstration site that allows very small scale deployment and management of technologies that later can be employed in the full-size national hydrometeorologic data acquisition and processing system. It provides the opportunity for hands-on experience crucial to assess the applicability of data acquisition technology to the agency's needs and its reliability in the local climate conditions and telecommunications environment.

At the conclusion of this phase the final technologies are selected for a pilot project.

2. **Pilot Project** – The pilot project is a small-scale implementation of the selected technologies to support an actual forecasting function in a high priority area. Through the implementation of the pilot project, agencies will gradually increase capacity for maintenance of all system components, refine estimates of costs, and refine the integration of system components.
3. **Initial National Networks** – An initial national network is implemented based on refinements from the pilot project. The initial network addresses additional priority areas.
4. **Expanded National Networks** – An expanded network is implemented in subsequent phases according to the capacity of the agencies and the development of requirements for forecasting. Stations identified for this phase are preliminary and subject to change based on needs.

The phases can be implemented concurrently by the individual EN countries, as suggested in ***Figure 6-1***. Regional cooperation and communication activities (spearheaded by ENTRO) can be part of each phase, ensuring that they are properly coordinated with the system's capabilities at all times. Continued and appropriately timed training and support should be provided during installation and operations activities.

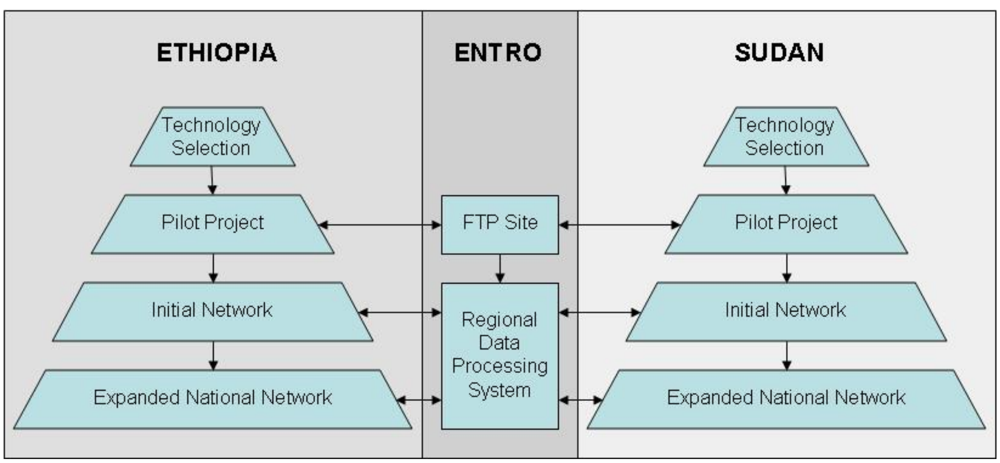

Figure 6-1: Project Phasing

Concurrent with the first phase implementation each country should undertake institutional preparation and development. Most importantly, agreements and protocols should be established between hydrology and meteorology agencies to assure cooperation and internal sharing of resources for efficient development of real-time climate and meteorological networks. One important outcome of this preparation is the identification of representatives from each agency to participate in the technology selection phase.

6.2 Institutional Setting

The most important factor in a successful data collection and forecast program is the effectiveness of the organization responsible for executing it – that is the staff that are expected to implement, operate, maintain, and apply the outputs of the program. No investment in hardware, software, civil works, and installation and consulting services will compensate for ineffective staff. On the other hand, a properly organized and motivated staff can overcome significant historical limitations to become effective in establishing a beneficial forecast and data collection program.

Many countries experience a common challenge of high employee turnover in which new staff without experience are hired and trained, but as they become effective in their duties they leave government service for higher paying jobs and fail to train their replacements (who are often not hired until after their departure). This can be especially challenging when the training has been provided by international consultants in connection with procurement and installation of hardware, software and systems and there is no local expertise to turn to for additional training of new staff.

The following recommendations outline steps that may be taken to establish an effective data collection and forecasting program and to create an environment that is conducive to maintaining a qualified, engaged staff for ongoing operation of the program.

6.2.1 Define Operational Mandate

A prerequisite to a successful hydrologic data collection and forecast program is a decision at a high level in the organization that it is an important function that merits investment of human and financial resources, which must necessarily come as a tradeoff with other potential functions. Experience has shown that when staff are assigned responsibilities for new initiatives and programs that compete with previously assigned duties and functions, they will often perform the new duties until there is a conflict, and then they will attend to former duties and respond to the priorities required by their supervisors. This is why high level commitment is essential to the development of a successful program. The following may be considered as key components of defining an operational mandate for an organization:

- An authoritative written directive that includes operational data collection and forecasting as a fundamental responsibility of the organization or some part of it.
- A statement of how the results and outputs of the system are to be used for the public benefit and to whom they will be disseminated
- An individual with responsibility, authority, capability, and resources to coordinate the data collection and forecasting functions
- Commitment of resources (budgets for staffing, operating, maintaining and expanding the program)

Definite flexibility exists in establishing these components. Operational data collection and forecasting may fall under an existing position where it has been under-emphasized in the past, but where the current officer chooses to make it a priority. In this case some thought must be given to steps that will be taken to assure program continuity when that official retires or departs. Alternatively, a senior officer may define a new mandate that includes operational forecasting and either assign it to existing officials or hire new staff to accept responsibility to perform the function. Finally, legislative bodies or individuals may create or update a mandate for the forecasting function and assign it to an existing organization or create a new organization. In any case, a successful program will require additional resources to be assigned or existing resources to be reassigned to begin performing a function that was not performed previously.

6.2.2 Assign and Maintain Key Staff Positions

With an organizational mandate and a coordinator (a key person assigned to coordinate the forecast and data collection program) key staff positions can be identified. It is not necessary to fill all of the positions at once, particularly as the program is developing, the network is small, and there are few forecast areas implemented. It is necessary, however to cover all of the functions identified by the key staff positions. As noted in the gap analysis, several functions are considered essential. For the forecast center:

- Hydrologist/hydrologic forecaster (2)
- Hydrometeorologist/forecaster (1)
- Computer systems expert (1)

For the data collection center

- Hydrographer (2)
- Data communications/telemetry expert (1)
- Computer systems expert (1)

The identified positions can be filled either by hiring or by identifying people within the organization who could be trained to perform the required functions. In any case, data collection and forecasting staff may be cross trained initially to provide the necessary redundancy during the early development of the program when all staff positions may not be filled. The computer systems expert may be shared between the two centers. To be most effective, all staff should have some hydrologic background or training. One of the hydrologic forecasters and one of the hydrographers could be identified as a manager to coordinate activities of the team.

Recognizing the likelihood of turnover even in the most stable of organizations, the organization needs to have flexibility and authority granted from the institution to rapidly replace staff who leave, preferably prior to their departure so that some overlapping training may occur with new staff.

Another approach to assist in dealing with turnover and training needs is to engage local consultants to maintain expertise that can be accessed for training new staff. If local consultants are frequently engaged in the development of system expansion and enhancements, they can provide some of the institutional memory and experience to bridge turnover at the organization.

In considering regular duties of forecasters and the need for training, it is important to note that for all of the Eastern Nile countries there is an extended period of the year when risks associated with flooding are minimal and operational responsibilities are minimal. These periods need to be utilized for development, including:

- Enhancements to computer systems
- Development and automation of data processing steps
- Investigation of new technologies and tools
- Training
- Extension of hydrologic forecast models to new areas
- Refinement and calibration of existing and new models
- Updating data processing systems to reflect changes in the data collection network
- Installation of new gauges
- Maintaining existing gauges
- Reviewing and refining rating curves

6.2.3 Institute Continuous Training Programs

To be effective, training must be considered a continuous process, both to increase capacity of each individual in the organization as well as to train new staff in basic duties, responsibilities, and technical capacity to perform their assigned functions. Several types of training programs are needed.

Although staff should be identified that are qualified to perform their duties, technical training is needed regularly for all staff. The *form* of the training can include:

- Internal training and mentoring from senior staff

- Cross training by staff performing complementary functions so that redundancy exists in the organization
- Internal training from local and international consultants (consultant is invited to train many people in the organization)
- External training from local and international consultants (individual staff are sent to outside training)

The *content* of the training will depend on specific duties, but should include the following topics:

- modern electronic monitoring stations and equipment (data loggers, electronic sensors, etc)
- telecommunications and telemetry, specifically on the systems in use
- real-time hydrometeorologic data processing
- computer systems and networks
- hydrologic forecasting and flood warning.
- Hydrometeorologic forecasting

Management training is important for staff with supervisory responsibilities. While this type of training may not be a high priority for the EN countries, the forecasting coordinator should recognize that the effectiveness of the forecasting program will depend on having a qualified and motivated staff. This will be easier to achieve in a productive work environment with reduced staff turnover. This can be achieved in part through application of appropriate management principles and practices.

6.2.4 Establish coordination among agencies

Meteorological forecasting is a vital government function that has its unique requirements for data that overlap with the data needs of hydrologic forecasting. Meteorological authorities in both Ethiopia and Sudan indicated a willingness to establish formal coordination and data sharing agreements but indicated that specific real-time data sharing arrangements did not exists. As hydrological services are expanded to include expanding real time data collection networks, coordination with meteorological authorities is needed. This coordination should include cooperation on location of precipitation stations operated by each organization, and formats, frequency, and means of communications for data exchange. Ideally, coordination regarding telemetry could be undertaken to share training and hardware costs.

6.2.5 Provide Funding

Funding is obviously required to maintain an effective program. Two key concepts are that staff turnover can be reduced by providing competitive salaries and that the scope of the program must not be allowed to expand beyond the funding available to support it.

Staff turnover is motivated by an individual employee’s search for better pay and improved working conditions. When salaries are adequate or generally competitive, working conditions generally become more important and employees are less likely to leave a positive, fulfilling workplace. Where pay is generally competitive but working conditions are poor and the environment is negative, employees will often accept lower pay that is still adequate in order to find a more positive work environment. A minimum standard of pay that is generally competitive is therefore required in addition to a positive work environment in order to retain staff.

Where funding is not sufficient to support the scope of a program, multiple program elements suffer and overall effectiveness is lost. Budgets must be increased so that there are enough staff and resources to sustain each phase of network expansion. Alternatively, reducing the scope of the program (limiting forecast areas or the number of stations that are being operated, for example) to be consistent with budgets will provide more effective delivery of services if budgets cannot be increased.

6.3 Ethiopia

6.3.1 Hydrologic Forecasting

The Gap Analysis identified a desired outcome for hydrologic forecasting that may be useful as Ethiopia and ENTRO move forward with development and enhancements to the existing hydrologic forecasting framework. Recommended forecast points for the forecast system are tied to the hydrometric stations recommended under the real time data collection network. Because the scope of the design for this study is confined to the data acquisition and communication systems, the forecast system design is not included in the implementation and procurement plan or any of the supplemental documents, except as it relates to the plans for data acquisition, processing, and communication systems requirements.

6.3.2 Data Collection Network

The implementation plan describes a phased approach to implementing an automated real-time hydro-meteorological data collection network to support hydrologic forecasting for flood warning.

6.3.2.1 Station Types

For purposes of the system design and for procurement, there are three station types designated. As the design of the system is refined in cooperation with the NMA, the selection of sensors for a given station can be modified as needs require.

Hydrometric Stations will include a water level sensor and a precipitation sensor. These stations are located on rivers at key locations and correspond to forecast points. In some cases, the precipitation measurement at these stations may not be representative of the surrounding area because they may be located in deep gorges with anomalous precipitation patterns compared with the surrounding area.

Precipitation Stations will include a rain gauge and a temperature sensor. These will form the majority of the precipitation network.

Meteorological Stations include a suite of sensors to measure meteorological parameters. Although none of these stations are specifically planned in the station design, the ministry may, in collaboration with the NMA, determine station locations from the design that could be candidates for additional sensors to meet the needs of NMA. The NFC should also consider incorporating data from any additional automated stations operated by the NMA into its data network for hydrologic forecasting.

6.3.2.2 Station Locations

Proposed station locations are presented below and organized according to the phases of implementation. Phase 1 consists of a single demonstration site near Addis Ababa showing sensors and data loggers, possibly from multiple vendors and using multiple telecommunications options to receive the data at a base station at MOWE. This will provide first-hand experience with the options from which the ministry can choose.

Phase 2 is a pilot data collection system including a network of precipitation and stream gauges around Lake Tana. The station locations include the Fogera and Dembia floodplains where the existing forecast system is defined, and include additional gauges on other rivers that enter Lake Tana. The stations identified for implementation in the pilot system are defined as priority 1 stations with hydrometric stations shown in ***Table 6-1*** and precipitation stations shown in ***Table 6-2***.

Table 6-1: Ethiopia Priority 1 Hydrometric Stations (Pilot implementation)

Label	Station Name	River	Latitude	Longitude	Status	Area
EH01R	Kola Diba	Dirma	37.3300	12.4800	New	-
EH02R	Chimba*	Gilgel Abbay	37.1600	11.7000	New	-
EH07	Merawi*	Gilgel Abbay	37.0300	11.3700	Existing	1,664
EH08	Azezo*	Megech	37.4500	12.4800	Existing	462
EH20	Addis Zemen*	Ribb	37.7200	12.0000	Existing	1,592
EH21	Bahir Dar*	Gumera	37.6300	11.8300	Existing	1,394

* Stations visited as part of this study

Table 6-2: Ethiopia Priority 1 Precipitation Stations (Pilot implementation)

Label	Station Name	Basin	Latitude	Longitude	Elevation
EM02R	Enjebara Pal	Gilgel Abbay	10.9800	36.9200	2,670
EM03R	Merawi	Gilgel Abbay	11.4100	37.1500	2,003
EM04R	Sekela	Gilgel Abbay	11.0000	37.2200	2,690
EM05R	Arb Gebeya	Gumara	11.6300	37.7400	1,800
EM06	Addis Zemen	Ribb	12.1300	37.7800	1,850
EM06R	Hamusit	Gumara	11.7800	37.5500	1,850
EM07R	Mekane Yesus	Gumara	11.6000	38.0600	2,384
EM08R	Woreta	Gumara/Ribb	11.9200	37.6800	-
EM09R	Amba Giorgis	Megech	12.7700	37.6000	2,900
EM10R	Gonder	Megech/Regional	12.5500	37.4200	1,967
EM11R	Bahar-Dar	Regional/Lake Tana	11.6000	37.4200	1,770
EM12R	Gassaie	Ribb	11.7900	38.1400	2,936
EM13R	Debre Tabor	Ribb/Gumara/Regional	11.8500	38.0100	2,690
EM16	Dangeta	Gilgel Abbay	11.2500	36.8300	2,000

* Stations visited as part of this study

Following the implementation of the pilot system and evaluation of the network, the Phase 3 implementation is planned, incorporating lessons learned and making needed changes to the design and specifications. Phase 3 represents an initial regional implementation for the Tekeze, Gambella and Abbay regions. The stations identified for implementation in the initial regional implementation are defined as priority 2 stations, with hydrometric stations shown in ***Table 6-3*** and precipitation stations shown in ***Table 6-4***.

Table 6-3: Ethiopia Priority 2 Hydrometric Stations (Initial National Implementation)

Label	Station Name	River	Latitude	Longitude	Status	Area
EH02	Asosa	Dabus	34.9000	9.8700	Existing	-
EH03	Arjo	Didessa	36.4170	8.6830	Existing	9,981
EH03R	Gamella Bridge	Baro	34.6209	8.2167		-
EH04	Nekemt	Angareb	36.5200	9.4300	Existing	-
EH04R	Baro Kella	Baro	34.9822	8.3632		-
EH10R	Shiraro	Tekeze	37.5200	14.1400	New	-
EH11	Bridge DS of Bagusta	Main Bele	36.3700	11.2800	Existing	-
EH14	Embamadre*	Tekeze (Setit)	38.2000	13.7300	Existing	-
EH16	Kessi Bridge*	Abbay	38.1800	10.0700	Existing	-
EH29	At Bure Bridge U/s of Mabil Da	Abay	37.0200	10.2900	New	-
EH30	Mendia Dam Site	Abay	35.5600	10.0700	New	-
EH40R	U.S. Abbay Conf	Dabus , Dabus	35.1500	10.6200		14,482
EH41R	Nr. Pawi	Beles, Main Beles	36.3330	11.2000		3,474
EH42R	Nr. Shambo	Finchaa, Finchaa	37.3830	9.5500		1,391
EH43R	At Kunzila	Abbay, Lake Tana	37.0000	11.9000	Existing	15,319
EH44R	Nr. Kessie	Abbay, Abbay	38.1830	11.0670		65,784
EH45R	Tekeze Dam	Tekeze River	38.6249	13.6269	New	-

* Stations visited as part of this study

Table 6-4: Ethiopia Priority 2 Precipitation Stations (Initial National Implementation)

Label	Station Name	Basin	Latitude	Longitude	Elevation
EM08	Alem Ketema		10.0300	39.0300	-
EM11	Arjo/Burecha Godana		8.7500	36.5000	-
EM14R	Bure	Baro	8.2300	35.1000	-
EM15R	Chira	Baro	7.5300	36.2000	-
EM16R	Dembidolo	Baro	8.5200	34.8000	1,850
EM17R	Gimbi	Baro	9.1700	35.7800	1,970
EM18	Debere Markos*		10.3300	37.6700	-
EM18R	Masha	Baro	7.7800	36.2800	1,640
EM19	Debre Birhan		9.6300	39.5000	-
EM19R	Mezan Teffri	Baro	8.2500	36.6000	2,000
EM20R	Shebel	Baro	8.3200	34.8000	1,525
EM21	Dedessa		9.3800	36.1000	-
EM21R	Shishinda	Baro	8.1000	36.9500	1,690
EM22	Teppi	Baro	8.0700	36.4500	1,950
EM22R	Yayo	Baro	7.7700	37.2300	2,400
EM23R	Yubdo	Baro	8.9300	35.1200	1,550
EM24R	Adigrat	Tekeze	14.0000	39.4500	2,280
EM25R	Axum	Tekeze	14.0000	38.7200	2,114
EM26R	Korem	Tekeze	12.5200	39.5200	2,456
EM27R	May Tsebri	Tekeze	13.7000	38.1800	-
EM28	Gore	Baro	8.1500	35.5300	2,002
EM28R	Shiraro	Tekeze	14.4000	37.7000	1,043
EM29R	Yechila	Tekeze	13.5200	38.7800	-
EM34	Mekane Selam		10.7500	38.7500	-
EM35	Mekele*	Tekeze	13.5000	39.4800	2,267
EM38	Nedjo		9.5000	35.4500	-
EM40	Nekemt		9.0800	36.4500	-
EM42	Sekota	Tekeze	12.6500	39.0300	1,850
EM44	Shire Endasilasse	Tekeze	14.1000	38.2700	1,912
EM60R	Pawe	Gilgel Abbay	0.0000	0.0000	-
EM61R	Jawe	Gilgel Abbay	0.0000	0.0000	-

* Stations visited as part of this study

After the initial regional implementation is complete, MWE should have sufficient experience to make any necessary adjustments to network characteristics as it plans for a final phase of ongoing expansion of the network to fill gaps in the spatial distribution of the network. Decisions can be made based on deficiencies identified in operating forecast systems using the observed data that are being received and applied. The final phase includes both priority 3 and priority 4 stations, which can be implemented over time according to available resources for equipment acquisition, installation, and maintenance of the growing network. The stations proposed for the network expansion are shown in ***Table 6-5*** and in ***Table 6-6***.

Table 6-5: Ethiopia Priority 3 and 4 Hydrometric Stations (Expanded National Network)

Label	Station Name	River	Latitude	Longitude	Status	Area	Priority
EH05R	Tule Benni	Baro	35.1500	8.5000	New	-	3
EH06	At Bahrdar*	Lake Tana	37.3800	11.6000	Existing	-	3
EH08R	Gilo	Gilo	34.2500	7.6300	New	-	3
EH17	At Bahradar	Abbay	37.4000	11.6000	Existing	-	3
EH18	Dam/Dumbong Villag	Alwero	34.6700	7.7700	Existing	-	3
EH19	Nr. Adi Kay	Gheba	39.0300	13.4700	Existing	-	3
EH22	At Abay Confluence	Jemma	38.5100	10.0500	Existing	-	3
EH31	Mekane Selam-Gundewein Br.	Abay	38.5200	10.9700	Existing	-	3
EH34	Shergole Cableway RGS	Abay	35.1500	10.6800	Existing	-	3
EH01	Nr. Abdi	Angareb	36.4700	13.7500	Existing	-	4
EH05	Nr. Metema	Goaing	36.1800	13.0000	Existing	-	4
EH12	Nr. Supe	Geba	35.6500	8.4800	Existing	-	4
EH24	Nr. Genda Wuha	Rahad	36.3700	12.4500	New	-	4
EH25	Nr. Sudan border	Angereb	37.2700	13.1200	New	-	4
EH25	Nr. Sudan border	Dinder	35.2700	11.9400	New	-	4
EH26	At Ribb Dam Site	Ribb	38.0000	12.0400	New	-	4
EH27	At Gumera Dam Site	Gumera	37.8100	11.7500	New	-	4
EH28	Nr. Lemi	Jemma	38.9000	9.9200	Existing	-	4
EH35	El Delm	Abay	35.1400	11.1500	Existing	-	4

* Stations visited as part of this study

Table 6-6: Ethiopia Priority 3 and 4 Precipitation Stations (Expanded National Network)

Label	Station Name	Basin	Latitude	Longitude	Elevation	Priority
EM02	Addis Observator		9.0000	38.7500	-	3
EM04	Adi Remet		13.7300	37.3300	-	3
EM07	Adwa		14.1700	38.8300	-	3
EM10	Ambo		8.9700	37.8700	-	3
EM13	Aykel WR		12.5300	37.0500	-	3
EM27	Gondar AP*		12.5500	37.2000	-	3
EM37	Mota		11.0800	37.8700	-	3
EM43	Shambo		9.5700	37.1000	-	3
EM46	Tepi		7.2000	35.4200	-	3
EM47	Wegel Tena		11.6000	39.2200	-	3
EM01	Abobo		7.8500	34.5500	-	4
EM03	Adet		11.2700	37.3700	-	4
EM05	Adigrat*		14.2700	39.4500	-	4
EM12	Asosa		10.0200	34.5200	-	4
EM14	Bahir Dar*		11.6000	37.2000	-	4
EM15	Chagni		10.9500	36.5000	-	4
EM17	Debark		13.1700	37.8800	-	4
EM23	Enewari		9.9000	39.1500	-	4
EM24	Finote Selam		10.6800	37.2700	-	4
EM25	Gambella		8.2500	34.5800	-	4
EM26	Gidayana		9.8700	36.9300	-	4
EM29	Humera		14.2800	36.5800	-	4
EM30	Kombolcha Nr Dessie		11.1200	39.7300	-	4
EM30R	Bedele		8.4500	36.3500	-	4
EM31	Lalibela		12.0300	39.0500	-	4
EM32	Maichew		12.8000	39.5300	-	4
EM33	Mankush		11.2800	35.2500	-	4
EM36	Metema		12.9700	36.1700	-	4
EM39	Nefas Mewcha		11.7300	38.4500	-	4
EM41	Pawe		11.1500	36.0500	-	4
EM45	Sirinka		11.7500	39.6000	-	4
EM51	Hamusit		12.6100	38.3300	-	4
EM52	Megech		12.5200	37.4700	-	4

* Stations visited as part of this study

The complete network is shown in ***Figure 6-2***.

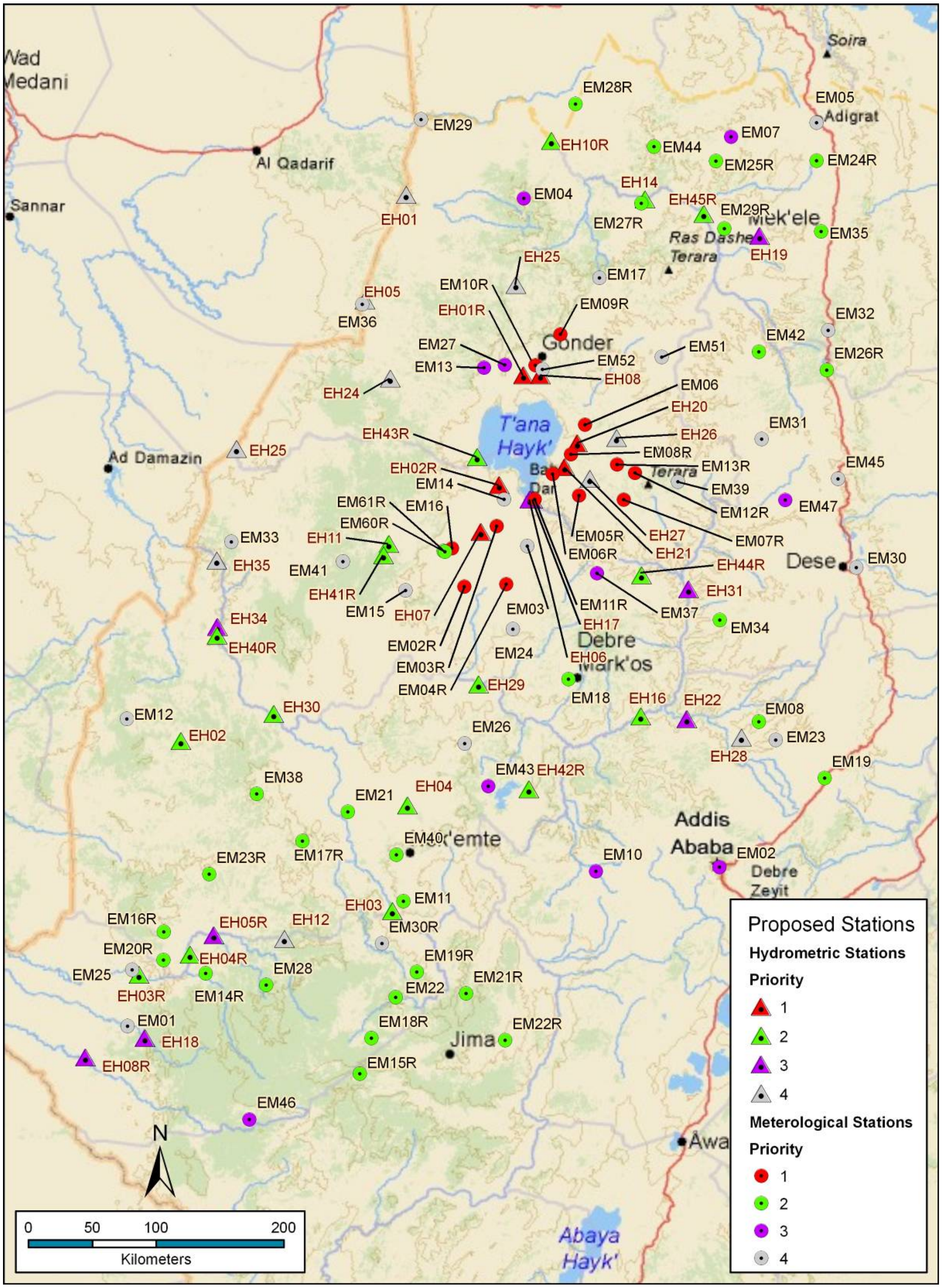

Figure 6-2: Proposed Ethiopia Data Network

6.3.2.3 Sensors

Riverside recommends a standard tipping bucket to measure precipitation for the proposed data collection network in Ethiopia. The tipping bucket provides good accuracy for flood forecasting and can be easily maintained once installed.

The type of sensor recommended for flow measurement depends on the conditions of the site. At existing sites which currently have a functioning stilling well, a shaft encoder is recommended. For sites near a bridge, and with suitable hydraulic conditions, a radar water level sensor is generally recommended. For sites where conditions are not suitable for water level measurement from a stilling well or a bridge, a bubbler water level sensor is recommended. The bubbler is useful in situations where high flows have a tendency to wash out equipment that is placed in the water, since the bubbler equipment can be located safely outside of the flow, while only an inexpensive tube is placed directly in the water. If washed away at high flows, the tube can be replaced relatively easily. It does, however, require additional maintenance. Additional sensors for meteorological parameters may be installed in close corporation with the NMA. A recommendation is included in ***Table 6-7.*** Initial suggestions regarding water level sensors for priority 1 and 2 hydrometric stations for Ethiopia are included at the end of the field study report in ***Appendix A***.

Table 6-7: Recommended Sensors for Ethiopian data collection network

Measurement	Recommended Sensor	Remarks
Flow	Shaft Encoder	If stilling well available
	Radar Water Level Sensor	If bridge available
	Bubbler Water Level Sensor	Other situations
Precipitation	Tipping Bucket	
Temperature	Thermocouple	
Wind	Anemometer	Including wind vane
Relative Humidity	Electronic	
Solar Radiation	Pyranometer	

6.3.2.4 Station infrastructure

A proper environment should be established and maintained for the equipment at a modern data collection station. The stations recommended for the data collection network will generally include a mast for mounting multiple sensors and antennae, a battery, solar panels, data loggers, some type of radio, and lightning and surge protection equipment. The station will therefore need a foundation for the mast, a fenced enclosure, an instrument shelter, and an instrument enclosure. Descriptions of these features are included in the specifications for the stations. It is generally anticipated that the ministry will be responsible for the civil works associated with this infrastructure, including fencing, foundations, and equipment shelters. Vendors of station equipment and their associated contractors will typically provide the remaining equipment, including instrument enclosures, wiring, conduit, connectors, solar panels, batteries, and surge protection equipment. It is critical to clarify in the tender documents what equipment will be provided by the contractor and what will be provided by MOWE.

6.3.3 Telemetry System

6.3.3.1 Recommended System

We recommend a Meteor Burst system as the primary telecommunications system for Ethiopia. Although there is a significant initial cost for the Meteor Burst master station, once it is installed new observing stations can be located almost anywhere in the Eastern Nile drainage of Ethiopia with only modest telecommunications cost for each station. Because of expected electromagnetic noise in Addis Ababa and other placement considerations, it is anticipated that the station will need to be located in an appropriate site to the east of the capital (such as Nazareth), with a microwave radio station to make the final link to a data collection center in Addis. In summary, the Meteor Burst option would permit secure data transmission with economical expansion and operating costs. The most involved elements of the associated technology are centralized at the master station and the radio communications to the data collection center, which eases institutional capacity development by allowing training to be focused on centralized staff.

It has been reported that Egypt has two Meteor Burst master stations, one of which is located at the High Aswan Dam. As part of the demonstration site proposed in phase II of the implementation strategy, it would be technically feasible to include a Meteor Burst transceiver at the demonstration site and configure the HAD master station to communicate with it, providing access to the data by internet. This would demonstrate the feasibility of the telecommunications protocol prior to the purchase, configuration, and installation of a master station in Ethiopia as part of the pilot project (phase III). Use of the Egyptian master station would require cooperation with the Egyptian authorities and may require installation of an additional antenna at the master station.

6.3.3.2 Satellite Alternative

If Ethiopia prefers not to use the Meteor Burst system, the most feasible alternative considered is *satellite transmission using METOSAT*. It possesses most of the same benefits as the Meteor burst system, with the exception of on-demand station polling and secure transmission. It has the additional advantages that the satellite infrastructure does not require maintenance by Ethiopia and that stations can potentially transmit random reports based on extreme observations. The primary drawback of the public satellite system is its lack of secure transmission.

It should be noted that if internet communications are not considered reliable enough to depend on for transmission of data from the receiving station in Darmstadt, Germany, then a separate satellite ground receiving station would be required, increasing initial implementation costs toward those of the Meteor Burst system.

6.3.3.3 GPRS/GSM Alternative

It would also be possible to implement a system based on the GPRS/GSM or other cellular network. This network is not available at all location in Ethiopia The GSM option would have a low initial cost but would be limited to locations where coverage exists. It may also be suitable for a pilot implementation, but inappropriate for a network of several hundred stations, where annual maintenance and transmission costs would negate the benefits of ease of setup in the early phases of implementation. It could be coupled with VHF radio to provide telemetry in areas without network coverage, but the complexities of the combined system at a national level might likewise negate the initial benefits.

6.3.3.4 VHF Radio Use

Another alternative is *VHF radio*. It is technically feasible, although it is typically better suited to smaller, more dense networks where the need for repeaters is minimized because of the close proximity of the stations and base station to one another. As such, for implementation as a national network in Ethiopia, it would require a detailed analysis of radio path at each phase of installation, would require multiple repeater stations, and would result in a complex network to administer with multiple disparate potential failure points. While this option might not be appropriate for the complete national network, its characteristics make it an ideal system for use in combination with other systems, as discussed previously.

6.3.4 Data Processing and Storage

A data processing and storage system located at the forecast center is recommended to facilitate review and analysis of observed data, supply the forecast system with required real-time data, and to store the data temporarily prior to archival in a long term historical database. The general requirements of the data processing and storage system have been discussed previously. Specific requirements will depend to some extent on the selection of telecommunications technology and the associated base station platform capabilities.

The Meteor Burst system will include a Master Station that permits a wide variety of options for configuring the data collection system and for polling stations and receiving reports.

The METEOSAT system will require either tools that can automatically download data from EUMETSAT over the internet or complete base station software if a dedicated ground receiving station is chosen.

The VHF radio system will also include a base station with basic capabilities for receiving and processing observed data.

In any case, it is recommended that the data processing system be acquired or developed as part of the pilot data acquisition system implementation, after the final selection of technology for telemetry is made. The specifications for the data processing system will include the functionality necessary to support communications with the regional data sharing center at ENTRO so that a separate system for regional communications will not be required.

Initially it may be feasible to use a single computer for both the telemetry base station and the data processing system. Ultimately it is recommended that two separate computers perform these functions, and that backup computers be provided for each function.

6.3.5 Regional Data Sharing

Regional data sharing functions will be included with the data processing system described previously. Prior to the implementation of the data processing system decisions should be made regarding the frequency and scope of data sharing with other EN countries through ENTRO.

6.4 Sudan

6.4.1 Hydrologic Forecasting

The Gap Analysis described a mature hydrologic forecast system with multiple features and inputs. Sudan has an existing hydrologic forecast system that is undergoing additional development. Riverside recommends that Sudan continue development toward a mature system, with specific emphasis on incorporation of a continuous hydrologic model integrated with a system for managing model states so that ongoing forecasts throughout the flood season are based on and consistent with evolving soil moisture conditions as they change in response to rainfall, evaporation, and drainage.

Recommended forecast points for the forecast system are tied to the hydrometric stations recommended under the real time data collection network. Because the scope of the design for this study is confined to the data acquisition and communication systems, the forecast system design is not included in the implementation and procurement plan or any of the supplemental documents, except as it relates to the plans for data acquisition, processing, and communication systems requirements.

6.4.2 Data Collection Network

The implementation plan describes a phased approach to implementing an automated real-time hydro-meteorological data collection network to support hydrologic forecasting for flood warning.

6.4.2.1 Station Types

For purposes of the system design and for procurement, there are three station types designated. As the design of the system is refined in cooperation with the NMA, the selection of sensors for a given station can be modified as needs require.

Hydrometric Stations will include a water level sensor and a precipitation sensor. These stations are located on rivers at key locations and correspond to forecast points.

Precipitation Stations will include a rain gauge and a temperature sensor. These will form the majority of the precipitation network.

Meteorological Stations include a suite of sensors to measure meteorological parameters. Although none of these stations are specifically planned in the station design, the ministry may, in collaboration with the NMA, determine station locations from the design that may be candidates for additional sensors to meet the needs of NMA. The NFC should also consider incorporating data from any additional automated stations operated by the NMA into its data network for hydrologic forecasting.

6.4.2.2 Station Locations

Proposed station locations are presented below and organized according to the phases of implementation. Phase 1 consists of a single demonstration site near Khartoum showing sensors and data loggers, possibly from multiple vendors and using multiple telecommunications options to receive the data at a base station at MWR. This will provide first-hand experience with the options from which the ministry can choose.

Phase 2 is a pilot data collection system of stream gauges on the Blue Nile between Ed Diem and Khartoum, including the Diner and Rahad tributaries. The stations identified for implementation in the pilot system are defined as priority 1 hydrometric stations shown in ***Table 6-8***.

Table 6-8: Sudan Priority 1 Hydrometric Stations (Pilot implementation)

Map Label	Station Name	River	Lattitude	Longitude	Status
SH13	Eddiem	Blue Nile	34.9255	11.2394	Existing
SH15	el Hawata	Rahad	34.5422	13.5929	Existing
SH16	Giweisi	Dinder	34.1023	13.3377	Existing
SH22	Khartoum Soba	Blue Nile	32.5955	15.5660	Existing
SH02R	Sennar	Blue Nile	33.6299	13.5603	Existing
SH03R	Medani	Blue Nile	33.5321	14.4093	Historical
SH06R	Roseires	Main Nile	34.3781	11.8830	Existing

Following the implementation of the pilot system and evaluation of the network, the Phase 3 implementation is planned, incorporating lessons learned and making needed changes to the design and specifications. Phase 3 represents an initial national implementation that extends the network to include a gauge at Malakal just upstream of a confluence with the White Nile, stations on the Main Nile from Khartoum to Dongola, and gauges in the Atbara basin. Precipitation stations are include in the higher rainfall areas near the Ethiopian border in the Blue Nile and Atbara basins. The stations identified for implementation in the initial national implementation are defined as priority 2 stations, with hydrometric stations shown in ***Table 6-9*** and precipitation stations shown in ***Table 6-10***.

Table 6-9: Sudan Priority 2 Hydrometric Stations (Initial National Implementation)

Map Label	Station Name	River	Lattitude	Longitude	Status
SH09	Kashm el Griba (2)	Atbara	35.9690	15.0638	Existing
SH11	Wad el Heleiw	Setit	36.0265	14.2132	Existing
SH12	Kubur	Atbara	35.7500	14.1900	Existing
SH23	Tamaniat	Main Nile	32.5596	15.9852	Existing
SH05R	Dongola	Main Nile	30.4935	19.1810	Existing
SH03	Atbara K3	Main Nile	34.0018	17.6797	Existing
SH01R	Malakal	White Nile	31.6500	9.5200	New
SH07R	Atbara	Main Nile	33.9695	17.6865	Existing
SH04R	Shendi	Main Nile	33.4303	16.7008	Existing

Table 6-10: Sudan Priority 2 Precipitation Stations (Initial National Implementation)

Map Label*	Station Name	Basin	Latitude	Longitude	Status
SM12	El Gadaref	Atbara	35.40	14.03	Existing
SM02	Abu Naama	Blue Nile	34.13	12.73	Existing
SM09	Ed Damazine	Blue Nile	34.40	11.82	Existing
SM01R	GHADAMBALIY	Rehad	34.98	14.03	Existing
SM02R	GAL EN NAHL	Rehad	34.95	13.63	Existing
SM03R	DOKA	Atbara	35.77	13.52	Existing
SM04R	J-MAZMUM	Blue Nile	34.67	12.07	Existing

The complete network for Sudan is shown in ***Figure 6-3***.

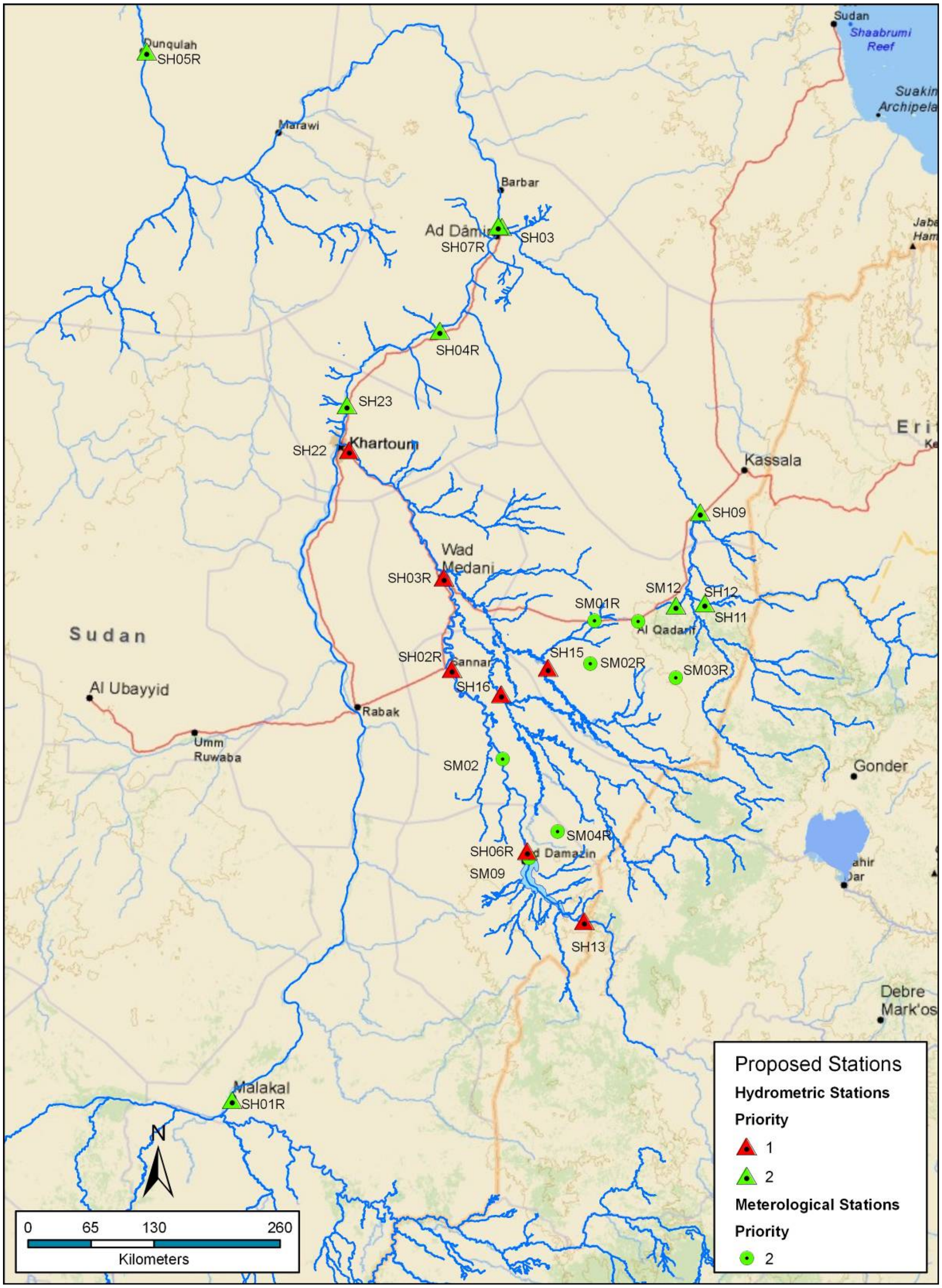

Figure 6-3: Proposed Sudan Data Network

Successful implementation and operation of the initial expansion network is expected to provide the essential information required for flood forecasting for the forecast areas. Phase 4 is therefore not explicitly defined for Sudan. It is expected, however, that future development, as well as use of the automated network for purposes other than flood forecasting will result in the need for additional stations. To grow the network efficiently to meet the additional demands on the network, it is recommended to automate remaining manually reporting stations as well as develop stations for the locations for which additional information is required.

After the initial regional implementation is complete, MWE should have sufficient experience to make any necessary adjustments to existing network characteristics as it transitions to a final phase of maintenance and ongoing expansion of the network to fill gaps in the spatial distribution of the network. Decisions can be made based on deficiencies identified in operating forecast systems using the observed data that are being received and applied. No station locations are identified for this phase. These locations will be more obvious to the Ministry after a period of operation of the forecast system using the existing network.

6.4.2.3 Sensors

Riverside recommends a standard tipping bucket to measure precipitation for the proposed data collection network in Sudan. The tipping bucket provides good accuracy for flood forecasting and can be easily maintained once installed. Due to the harsh climatic conditions the sensors will experience, regular maintenance of the equipment will be required.

The type of sensor recommended for flow measurement depends on the conditions of the site. At existing sites which currently have a functioning stilling well, a shaft encoder is recommended. For sites near a bridge, and with suitable hydraulic conditions, a radar water level sensor is generally recommended. For sites where conditions are not suitable for water level measurement from a stilling well or a bridge, a bubbler water level sensor is recommended. The bubbler is useful in situations where high flows have a tendency to wash out equipment that is placed in the water, since the bubbler equipment can be located safely outside of the flow, while only an inexpensive tube is placed directly in the water. If washed away at high flows, the tube can be replaced relatively easily. It does, however, require additional maintenance.

Additional sensors for meteorological parameters may be installed in close corporation with the NMA. A recommendation is included in ***Table 6-11.*** Due to the dust storms that are common in parts of Sudan, the anemometer wind sensor is likely to require frequent maintenance in order to operate satisfactory. Sensor models with high quality seals should be procured. The ultrasonic wind sensor, which has no moving parts, is a more expensive option that should function with less maintenance. We recommend that Sudan gain experience with both anemometers and ultrasonic wind sensors and determine which is most appropriate, considering the balance between initial cost and long term maintenance. Because of the intense heat that is common in Sudan, Riverside also recommends that electronic equipment be rated for extended temperature ranges.

Table 6-11: Recommended sensors for Sudan data collection network

Measurement	Recommended Sensor	Remarks
Flow	Shaft Encoder	If stilling well available
	Radar Water Level Sensor	If bridge available
	Bubbler Water Level Sensor	Other situations
Precipitation	Tipping Bucket	
Temperature	Thermocouple	
Wind	Anemometer	Including wind vane
	Ultrasonic sensor	Testing purposes
Relative Humidity	Electronic	
Solar Radiation	Pyranometer	

6.4.2.4 Station infrastructure

A proper environment should be established and maintained for the equipment at a modern data collection station. The stations recommended for the data collection network will generally include a mast for mounting multiple sensors and antennae, a battery, solar panels, data loggers, some type of radio, and lightning and surge protection equipment. The station will therefore need a foundation for the mast, a fenced enclosure, an instrument shelter, and an instrument enclosure. Descriptions of these features are included in the specifications for the stations. It is generally anticipated that the ministry will be responsible for the civil works associated with this infrastructure, including fencing, foundations, and equipment shelters. Vendors of station equipment and their associated contractors will typically provide the remaining equipment, including instrument enclosures, wiring, conduit, connectors, solar panels, batteries, and surge protection equipment. It is critical to clarify in the tender documents what equipment will be provided by the contractor and what will be provided by MOIWR.

6.4.3 Telemetry System

6.4.3.1 Recommended system

We recommend a telemetric system based on *satellite transmission using METOSAT*. Because the infrastructure associated with this satellite transmission is sustained by the international meteorological community, the initial hardware cost of these systems is comparable to GPRS/GSM and VHF radio, without the need for ongoing transmission costs or expensive radio path studies. New observing stations can be located almost anywhere in the country with only modest telecommunications cost for each station. The METEOSAT option would permit reliable data transmission with economical expansion and low implementation and operating costs. The transmission frequencies available (hourly, 3-hourly) are adequate for forecasting requirements in Sudan.

6.4.3.2 Meteor Burst Alternative

A feasible alternative to satellite transmission is a Meteor Burst system as the primary telecommunications system for Sudanese stations. Although there is a significant initial cost for a Meteor Burst master station, once it is installed new observing stations can be located almost anywhere in the Eastern Nile drainage of Sudan with only modest telecommunications cost for each station. Because of expected electromagnetic noise in Khartoum and other placement considerations, it is anticipated that the station would need to be located near the border with Egypt with an alternate link (internet would be possible) to a data collection center in Khartoum. The Meteor Burst option would permit secure, reliable data transmission with economical expansion and operating costs, but with a higher initial cost than the satellite option.

It has been reported that Egypt has two Meteor Burst master stations, one of which is located at the High Aswan Dam. As part of the demonstration site proposed in phase II of the implementation strategy, it would be technically feasible to include a Meteor Burst transceiver at the demonstration site and configure the HAD master station to communicate with it, providing access to the data by internet. This would demonstrate the feasibility of the telecommunications protocol prior to the purchase, configuration, and installation of a master station in Sudan as part of the pilot project (phase III). Use of the Egyptian master station would require cooperation with the Egyptian authorities and may require installation of an additional antenna at the master station. As a lower cost alternative, arrangements could be made with Egypt to share the use of the master station for both Egyptian and Sudanese reporting stations.

6.4.3.3 GPRS/GSM Alternative

It would also be possible to implement a system based on the GPRS/GSM or other cellular network. This network is not available at all location in Ethiopia The GSM option would have a low initial cost but would be limited to locations where coverage exists. It may also be suitable for a pilot implementation, but inappropriate for a network of several hundred stations, where annual maintenance and transmission costs would negate the benefits of ease of setup in the early phases of implementation. It could be coupled with VHF radio to provide telemetry in areas without network coverage, but the complexities of the combined system at a national level might likewise negate the initial benefits.

6.4.3.4 VHF Radio Use

VHF radio is not considered economically feasible for Sudan because of the large distance between stations and from stations to a data collection center. While this option would not be appropriate for the complete national network, its characteristics make it an ideal system for use in combination with other systems, as discussed in chapter 5 Network Design Considerations.

6.4.4 Data Processing and Storage

A data processing and storage system located at the forecast center is recommended to facilitate review and analysis of observed data, supply the forecast system with required real-time data, and to store the data temporarily prior to archival in a long term historical database. The general requirements of the data processing and storage system have been discussed previously. Specific requirements will depend to some extent on the selection of telecommunications technology and the associated base station platform capabilities.

The METEOSAT system will require tools that can automatically download data from EUMETSAT over the internet.

The Meteor Burst system will include a Master Station that permits a wide variety of options for configuring the data collection system and for polling stations and receiving reports.

The GPRS/GSM system will require tools that can automatically download data from the entity that provides the communications.

In any case, it is recommended that the data processing system be acquired or developed as part of the pilot data acquisition system implementation, after the final selection of technology for telemetry is made. The specifications for the data processing system will include the functionality necessary to support communications with the regional data sharing center at ENTRO so that a separate system for regional communications will not be required.

Initially it may be feasible to use a single computer for both the telemetry base station and the data processing system. Ultimately it is recommended that two separate computers perform these functions, and that backup computers be provided for each function. Specific features of the data processing system were presented in *Chapter 5 Network Design Considerations* and are repeated in the specifications.

6.4.5 Regional Data Sharing

Regional data sharing functions will be included with the data processing system described previously. Prior to the implementation of the data processing system decisions should be made regarding the frequency and scope of data sharing with other EN countries through ENTRO.

6.5 Egypt

6.5.1 Hydrologic Forecasting

Riverside recommends that Egypt evaluate the benefits of updating reservoir modeling in the Nile Forecast system s to include the Tekeze dam on the Tekeze River in Ethiopia, the Merawi Dam on the Main Nile in Sudan, and the raising of Roseires Dam on the Blue Nile in Sudan. The upstream dams in the Eastern Nile region have a collective impact on peak flows and timing of inflows into the High Aswan Dam and should be considered for implementation. Egypt will depend on Sudan and Ethiopia to provide information regarding the operating capabilities and operating policies of the reservoirs. Essential information includes the following:

- Storage – elevation curves for each reservoir
- Monthly or seasonal pool elevation targets

- Minimum monthly releases (for hydropower generation or for ecological flows)
- Maximum discharge capacity as a function of elevation

The specific policies for reservoir operation will alter the specific information required for adequate simulation for the NFS, and the rules may change over time, especially during the first few years of operation of the dams.

6.5.2 Data Collection Network and Telemetry System

The implementation plan describes a phased approach to implementing an automated real-time hydro-meteorological data collection network for Ethiopia and Sudan. Both countries will require a telemetry system and need to make decisions regarding that system. Egypt could provide assistance to the other EN countries in evaluating telemetry options by permitting visits to review existing systems operated in Egypt, including both satellite and meteor burst systems.

Egypt should coordinate with Sudan regarding automating it's existing gauges within Sudan so that the effort is coordinated with aspects of the Sudanese network, especially the telecommunications component. No specific gauges are proposed for automation for Egypt.

6.5.3 Data Processing and Storage and Regional Data Sharing

Egypt should monitor the progress of ENTRO in establishing a regional data sharing system and make the necessary adjustments to its data processing capability to enable upload of satellite based precipitation grids to the center and.

6.6 ENTRO

ENTRO's primary roles are to coordinate data sharing, to provide technical backstopping, and to offer procurement support.

6.6.1 Data Sharing

Riverside recommends that ENTRO develop a data processing system designed to receive and disseminate real-time observed hydrometeorological data among the EN countries via the internet. Consistent with the phased approach to implementation, we recommend that ENTRO establish an FTP site concurrent with the Phase 2 Pilot implementations in Sudan and Ethiopia and initiate data sharing protocols (data and file formats and naming conventions) that each country can use to initiate data sharing on a limited basis using data from the prototype systems.

During the Phase 3 implementations in Sudan and Ethiopia it is recommended that ENTRO proceed with the deployment of an expanded regional data processing system based on an evaluation of the capabilities and features of the national data processing systems and adding any capability that will improve ENTRO's ability to support the individual countries and enhance the data sharing activities. Inasmuch as the Phase 2 Pilot implementations for each country will include data processing components, ENTRO should work closely with each country to understand the selected data processing software to inform ENTRO's subsequent procurement and implementation of a data processing system. This will then have the dual benefit of providing ENTRO with data processing capability and allowing ENTRO to provide backup support to the countries in the use and application of data processing systems.

Maintaining a data processing center will require existing facilities and new installations to be configured to provide 24-hour operations. As part of both the phase 2 and phase 3 implementations ENTRO should review its communications and backup power systems to confirm that a high system reliability can be achieved.

6.6.2 Technical Support

The Gap analysis indicated that in spite of discontinuing the RFCU, ENTRO has maintained a positive support function and capability in flood coordination. Continued emphasis is needed to demonstrate support for the flood coordination function, to clearly articulate its ongoing goals and objectives, and to clarify responsibility for flood coordination in the organizational structure. Riverside recommends that ENTRO clarify the way in which the flood coordination function will be satisfied as part of its remaining functions and identify the staff positions that will be specifically assigned to continue these functions.

6.6.3 Institutional Development

ENTRO's historical role has not included an operational mission as a major component of its activities. While the regional data sharing function may not be as time-sensitive as flash flood data processing needs in Ethiopia, it is vital that any potential lapses in service be addressed immediately to permit continuous access by the countries that depend on the data. ENTRO therefore should formally identify the existence and scope of an operational mission, together with the associated duties and responsibilities. This mission should be evaluated after one year of operation of the implemented data processing system to determine if the function should be retained permanently or scheduled to be taken on individually by the countries. As part of the operational mission ENTRO will need to either to hire or contract for real-time data processing services or to obtain training necessary for existing staff to take on these functions.