Nile Basin Initiative
Eastern Nile Subsidiary Action Program (ENSAP)
Eastern Nile Technical Regional Office (ENTRO)

Eastern Nile Watershed Management Project

Design of Sediment Monitoring System for Eastern Nile Countries

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Annex 4: Photos from Abbay and Tekeze Field Trips, Ethiopia

Acronyms

ADCP	Acoustic Doppler Current Profiler
AHDA	Aswan High Dam Authority
BIS	Basin Information System
CRA	Cooperative Regional Assessment
DIU	Dams Implementation Unit
DSS	Decision Support System
EN	Eastern Nile
ENPM	Eastern Nile Planning Model
ENSAP	Eastern Nile Subsidiary Action Program
ENTRO	Eastern Nile Technical Regional Office
ENWMP	Eastern Nile Watershed Management Program
GPS	Global Positioning System
GWWD	Ground Water and Wadis Directorate
HRS	Hydraulic Research Station
HIS	Hydrology Information System
IDEN	Integrated Development of the Eastern Nile
LNNMF	Lake Nasser/Nubia Management Framework
MoWE	Ministry of Water and Energy
NBI	Nile Basin Initiative
NRI	Nile Research Institute
NELSAP	Nile Equatorial Lakes Subsidiary Action Program
NMA	National Meteorological Agency
OCC	Overhead Cable Car
PID	Project Identification Document
RTK-GPS	Real Time Kinematics Global Positioning System
SAP	Subsidiary Action Programme
SVP	Shared Vision Planning

SVR	Surface Velocity Radar
SWQMN	Sediment and Water Quality Monitoring Network
ToR	Terms of Reference
USGS	US Geological Survey
WMO	World Meteorological Organisation

1 Introduction

Two individual Consultants have been engaged by ENTRO for the Design of Basin wide Sediment and Water Quality Monitoring Systems with a guideline on harmonized standard and methods. Contracts were signed individually with ENTRO, with commencement set at 5th June 2011. Due to public holiday in Sweden and Ethiopia, the Consultants arrived at ENTRO a few days later, on 8th June 2011. After revision of the work plan September 2011, the assignments were scheduled for completion late February 2012.The Consultants are:

Mr Carsten Staub (Hydrologist and Team Leader)
Dr Per-Olof Seman (Water Quality Specialist)

It was the intention that the Consultants would work closely together, doing some of their field work jointly, but it turned out impractical and inefficient to do joint field trips, so these were mainly done separately. Also reports are submitted separately before they are joined together in one joint report. The Water Quality Specialist submits his report first, and the Hydrologist/Team Leader incorporates the report of the Water Quality Specialist in his report. The present Draft Final report on the Design of a Sediment Monitoring System does not include water quality issues, and is the individual report of the Hydrologist. The present Design of Sediment Monitoring System for Eastern Nile Countries is submitted approximately 8 months after commencement of the assignment.

2 Background

2.1 Overview of the EN Basin Programmes

A strategic action programme has been launched to translate the NBI's shared vision into action. This consists of two complementary sub-programmes; a Shared Vision Programme of technical assistance and basin wide capacity building projects to create an enabling environment for cooperative development, and Subsidiary Action Programmes (SAPs) carried out by smaller groups of Nile riparian states, comprising of physical investment at sub-basin level involving two or more countries.

Two groupings for such programmes have formed; one within the Eastern Nile including Egypt, Sudan and Ethiopia (ENSAP[1]) with Eritrea as an observer, and the other covering the Nile Equatorial Lakes Region with the six countries in the southern portion of the basin as well as Sudan and Egypt (NELSAP). Figure 1 shows the Eastern Nile Basin. The Project Identification Document (PID) for ENSAP, approved by the Eastern Nile Council of Ministers in March 2001, establishes the long-term goals and objectives for the first ENSAP investment program for the Integrated Development of the Eastern Nile (IDEN).

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[1] Eastern Nile Subsidiary Action Program (ENSAP) – Project Identification Document, Eastern Nile Council of Ministers, 2001

Figure 1 Eastern Nile Sub-basins

ENSAP has the objective to:
"*ensure efficient water management and optimal use of the resources through the equitable utilization and no significant harm; ensure cooperation and joint action between the Eastern Nile Countries seeking win-win goals; target poverty eradication and promote economic development; and to ensure that ENSAP results in a move from planning to action*" .

The PID has outlined seven potential areas of cooperation. One of the seven areas of cooperation agreed upon by the Eastern Nile Riparian Countries is integrated Watershed Management.

The long term objective of the **Eastern Nile Watershed Management Program** (ENWMP) is to improve the standard of living of the populations residing within the selected watersheds of the Nile basin, reduce *soil and water loss*, improve agricultural productivity increase food security, *decrease sediment transport and reduce siltation of reservoirs and canals, reduce erosion and morphological changes along the river*s, and decrease pressure on natural resources.

To achieve the above objectives the countries have embarked on two parallel programmes, explicitly the Cooperative Regional Assessment (CRA) and the Fast Track projects. While the CRA is an effort for identifying long term opportunities for cooperative actions, the fast track watershed projects aim at demonstrating early results of on the ground improved watershed management.

Thus, the objectives of the current assignment fits well into the overall objectives of the ENWMP and specifically the Consultants will focus on establishing *a watershed management data and information system; to be able to undertaking a coordinated sediment and water quality monitoring for the Eastern Nile Basin*. The assignment will cover the Eastern Nile Basin as depicted in *Figure 1.*

2.2 Design of Basin-Wide Sediment Monitoring System

This section discusses the importance of the present programme.

Resource degradation processes in Eastern Nile countries have impacts not only locally, but far downstream within and beyond the borders of the country within which they occur. The most significant impacts of land degradation in the Eastern Nile Basin are:

- loss of soil productivity because of accelerated erosion of the top soil,
- increased siltation of reservoirs for hydropower and irrigation as well as siltation of irrigation canals
- deteriorating water quality due to increased suspended load and sedimentation

In the absence of adequate integrated watershed management interventions, soil erosion and degradation of natural resources will continue at accelerating rates, reducing agricultural productivity and affecting household economies. The impact of soil erosion and degradation has not only economic, but also social and political consequences.

Soil erosion leads to increased sediment loads of streams and rivers. As a result, there is increased siltation of major reservoirs for irrigation and hydropower generation, reducing their efficiency and useful life. This situation is sometimes mitigated through costly de-silting operations. The high sediment loads have considerable negative impacts including sedimentation of dams, reservoirs and canals in irrigation schemes leading to reservoir storage loss, increased costs for removal of sediment for domestic water supplies, damage to hydro-electric turbines and irrigation pumps, higher irrigation-system operation and maintenance costs, increased dredging in front of turbines in-takes, higher cost of water purification, pump damage, river bed aggradations, lost hydroelectricity production and losses in agricultural production.

In addition to flood-carried sediment, the basin areas in Sudan and Egypt are threatened by serious sand encroachment. The sand encroachment and resulting sand deposition into the Nile have created numerous problems. It has been reported (e. g. Dafalla et al (2007) and El Moatassem) that substantial amounts of sand are pouring into Lake Nasser/Nubia every year, decreasing the storage capacity. Moving sands of different sizes (fine and medium) from different sources have occupied vast areas of lands, burying inhabited localities, houses, roads, farms, canals, watercourses and other resources, and loss of large areas of valuable agricultural lands. The quantification of the sediment volumes involved in sand encroachment is difficult but also very important in order to include this volume in the total sediment balance.

Accurate prediction of erosion (under different land use/management practices), sediment transport and the associated impact on water quality is a key to solutions in terms of sound watershed plans that will reduce soil erosion in the critical areas, thereby with time reducing downstream impacts. However, available data in the basin is scanty and whenever this is available it is reported to be of poor quality making planning at a larger scale difficult. Thus, there is a need to accurately document the level of erosion and sedimentation both in time and space and (if possible) to establish relationship between land use/management and sediment transport. The quantification of soil erosion is based on empirical formulas that need to be tuned to each geographical location. And the quantification of sediment transport rates in flowing water is still a semi-empirical science that relies more on measurements than any other hydrological/hydraulic discipline. At the same time, for several reasons, the uncertainties in sediment transport measurements is far higher than for measurements of hydrometric parameters, such as discharges. Thus, accuracies of sediment transport predictions are bound to be relatively low, but still necessary and very useful in the evaluation/assessment of development options.

The basin-wide erosion and sediment transport monitoring is envisaged to establish within ENTRO a system to systematically collate and store relevant data and information for effective watershed management planning, monitoring, evaluation and undertaking environmental, social and economic impact studies. Assessment of impacts will include physical, social and economic characteristics. The monitoring system will establish a long-term coordinated system of monitoring of erosion and erosion control; sediment loads and land cover change at various catchment scales.

Monitoring of suspended sediment loads throughout the sub-basin at the outlets of micro-catchments, sub-catchments and catchments of varying size will provide input to research to develop a more complete understanding of the linkages between catchment size, geomorphology, soils and land use and the dynamics within the sub-basin. Since it may not be feasible to undertake this across the whole basin, a number of hydrologically-linked micro- and sub-catchments may be selected (representative of specific agro-ecological and livelihood systems) and studied in detail to obtain a deeper understanding of the impacts of watershed management interventions.

It will be important that the cooperative data and information collection and research results are well integrated and coordinated across the basin to achieve maximum synergy. There are also implications for capacity building and institutional strengthening at various levels to support these cooperative activities.

The problems related to soil erosion/sedimentation vary greatly from one area to another.

In Ethiopia, with high and heavy rainfall, steep slopes and erodible soils, the problem of soil erosion and the associated loss of agricultural production is so far the dominating one. In the near future the several new dam projects will have to deal with the high sedimentation rates in some of the reservoirs and the associated bank erosion downstream.

In Sudan, with its less steep terrain, soil erosion is less common although it is still a problem in some areas. Siltation in existing reservoirs is high and the same is the case for siltation of irrigation canals. A problem that is specific to Sudan is the sand encroachment of river Nile in the lower part of the Nile, from downstream of the Atbara confluence to Lake Nubia/Nasser. Wind-blown sand settles within the river cross section and enters into the sediment balance of the river. Sand encroachment creates problems locally, by for instance enhancing local flooding and it enters the sediment balance of the Nile, changing the river regime and eventually contributes to the sedimentation in Lake Nubia/Nasser. The sedimentation in Lake Nubia is not seen as a negative impact in Sudan. Here the sedimentation contributes to the development of fertile agricultural land in the new delta that is forming in the Lake Nasser/Nubia. Any use of fertilisers and/or pesticides, in connection with agricultural activities close to the river will impose a risk to the water quality downstream.

Egypt is the country on the ‘receiving end’. The sedimentation in Lake Nasser/Nubia depends on the soil erosion and sediment transport rates including bank erosion and sand encroachment further upstream in Sudan and Ethiopia, and since recently also on the new upstream dam projects under implementation (Merowe is still impounding). But downstream of Lake Nasser/Nubia the sediment balance is affected only by conditions imposed within Egypt, i. e. the sediment trapping by Lake Nasser/Nubia.

The status of monitoring of sediment erosion/transport/deposition in the three countries is likely to reflect the past local need of this data, whereas a new improved monitoring system should take into account downstream effects and changes in the local data need. This can be illustrated by an example: It may be beneficial to try to locate the main soil erosion sources in the upstream river reaches (mainly Ethiopia), in addition to monitoring the development of the downstream consequences.

3 Objectives

According to the ToR:

The over-arching goal of the consultancy service is to establish a basin wide sediment monitoring system in order to assess the level of erosion and sedimentation rate and determine the impacts (short- and long-term, positive and negative) of the Watershed Management Projects in the basin on erosion, and sedimentation rates.

The preceding introductory text of the ToR indicates that deteriorating water quality is due to increased suspended load and sedimentation. It is true that increased suspended load in itself causes water quality to deteriorate, but deteriorating water quality for other reasons, unrelated to sediments, may be at least as serious. In the present assignment we have chosen to consider the sediment and the water quality issues as separate and largely unrelated.

The ToR continues to describe how the goal will be achieved:

This goal is to be achieved through two phases of the project. Phase I, which specifically aims at reviewing of existing situation, identification of gaps and planning of follow-up activities and Phase II, which will focus on designing of a basin-wide sediment monitoring system, development of guideline for the harmonization of standards and development of data management system.

Phase II will be carried out in two Parts: While Part I will concentrate on designing of the monitoring framework (discharge, sediment and water quality) and development of a guideline on harmonized standards and methods on data collection and quality check for information and data sharing among the three EN countries, Part II will focus on the development of basin-wide sediment data management system.

Specific objectives of Part I of Phase II are:

1. ***Design a basin-wide monitoring system for sediment/erosion***
2. ***Develop a guideline on a harmonization of standards and methods on data collection and quality check for information sharing on sediment monitoring***
3. ***Recommend institutional setup to manage the monitoring activities for each of the three EN countries***

The two-phased approach is a classical one: A thorough review of the existing conditions serves to identify the gaps in the existing monitoring system setup, in order to be able to focus improvement efforts where the benefits will be the most significant. In the Consultant's approach, model simulation of sediment transport and water flows play a major role: By adapting the monitoring efforts to satisfy the needs of modelling systems, reliability is enhanced and monitoring efforts can be kept at a minimum.

4 Approach and Scope of Work

4.1 General

It is important to ensure that recommendations on the design of monitoring and data storing/sharing systems correspond well with defined needs in the EN countries. The Consultant has therefore visited all EN countries for discussions of ideas and suggestions. Meetings have been held with officials both at decision level and at technical level in all three countries, and a number of field visits to monitoring stations have been conducted.

Meetings with decision makers would identify ongoing and future projects with a need for quality data and/or would have an impact on sediment transport. Such ongoing projects as well as future projects presently in the pipeline could affect the Consultant's recommendations on a future monitoring system. Also the requirements and needs with respect to data sharing were explored in these meetings, and taken into account in recommendations for future data base setup and data sharing procedures.

Meetings with the technical specialists serve to identify wishes and ideas for improvements that would increase quality and/or capacity of the agencies responsible for carrying out the measurements and taking care of the measured data. Another purpose was to meet with technical organizations working with the more high-tech, front-end solutions when it comes to measuring techniques as well as data handling, processing and storage. In case these methodologies are found suitable for larger areas, it may be recommended to expand their use to other areas/countries. Revisiting has also taken place to complement earlier collected data.

It was important that the visits as described were carried out as early as possible in the assignment in order for the Consultants to take on board the views of national stakeholders in all countries in their work.

The Consultants have worked closely with ENTRO throughout the assignment, through meetings with the Coordinator at ENTRO, Dr Solomon Abate and other ENTRO staff, during visits to Addis Ababa.

4.2 Water and Sediment

The sediment is carried by the flowing water, which means sediment transport is closely related to the flow velocities and discharge. Therefore, measurements of sediment transport in the rivers should preferably be done simultaneously with discharge measurements. This even applies for sediment transport measuring methods that do not require a flow measurement; the reason being that the relation between flow and sediment transport (sediment rating) is important in the prediction of the sediment transport pattern.

Measuring stations should be carefully selected, keeping in mind that all measurements should be done with a purpose. Examples are:

- Sediment transport monitoring in the rivers downstream of areas with high soil erosion potential may be used to check trends (say after erosion reducing measures have been implemented).

- Sediment transport measurements and sedimentation monitoring in deposition areas may be used to map the sedimentation consequences to upstream erosion.

- Less frequent sediment transport measurement in rivers where sediment transport is presently low is justified as a check for any rising trends

Locations of measuring stations should be selected carefully, at relatively stable cross sections. Measuring results from instable river reaches are hard to interpret, which means results may be misleading.

Hydraulic and sediment transport modelling are important and necessary tools in the planning and analysis of impacts of project implementations. Measured data are not useful in this respect in itself. But quality data is the most important requirement of the model. The monitoring setup therefore needs to satisfy the data required for the modelling. This may be ensured by reviewing ongoing modelling in the EN countries, and subsequently adjusting the monitoring programmes. By use of hydrologic/hydraulic and sediment transport models, monitoring efforts can be minimized. The modelling of sediment transport in the rivers, taking into account the morphological changes is, however, a very complex task and it is therefore advisable in sediment transport modelling to measure more than strictly required by the models.

An important and reliable method that – combined with some theoretical/empirical estimations – can be used to assess the sediment load of a river, is bed level survey of reservoirs on the river, so-called bathymetric surveys. Such surveys will even provide important information to the reservoir owner about the sedimentation rate of the reservoir. Theoretical/empirical methods and/or mathematical modelling may be used to assess how large volumes of the sediment that arrives at the reservoir will be carried through the dam.

5 Review of Present Conditions

5.1 General

The present conditions in EN countries have been comprehensively reviewed by the Phase I Consultants in Egypt, Sudan and Ethiopia. The present Consultant, however, did his own limited investigations in each country.

For the sediment monitoring, more emphasis has been given to Ethiopia, since Ethiopia is the main source of the sediment transported by the Nile and its tributaries. More limited investigations were done in Sudan, and even less in Egypt.

5.2 Comments on Phase I Findings on Sediment Monitoring

Phase I findings are commented on, only to the extent that the present Consultant has something to add or has a deviation in opinion. It has to be noted that the Phase I Consultants did a comprehensive study of the present conditions, whereas the present Consultant did more sporadic studies of the existing condition, to a large extent guided by the outcome of the Phase I study.

5.2.1 Phase I Ethiopia

Phase I: It has been suggested to conduct regularly (every 6 to 8 weeks) condition assessment of hydrometric stations and inspection of observer books.

Comment: Monitoring staff or gauge readers should check for any damages/malfunctions of the station when they are there. Observations of such should be reported to the Hydrology and Water Quality Directorate. Regarding the observer books, it is understood that these are normally made available to the Hydrology and Water Quality Directorate every 3 months. This is a long time span; it should be reduced to 1 month and the observer books should be inspected by Hydrology and Water Quality Directorate staff as soon as they arrive, so necessary corrections can made.

Phase I: It has been said that the Hydrology and Water Quality Directorate needs to continue as a core major department under the MoWE, where all other departments (irrigation, hydropower, water supply, basin studies, transboundary, etc) strongly linked with Hydrology and Water Quality Directorate as their activity is highly dependent on the hydrologic information that are measured, processed, analyzed and disseminated to them or to the consultants employed by them.

Comment:

Agreed, but when modeling is introduced there will be major benefits in having the essential input data for the models under the same institution, along with the modeling itself. Meteorological data are important input to the models and it would be advantageous to integrate the Hydrology and Water Quality Directorate with the National Meteorological Agency (NMA) – still under the MoWE. According to the NMA director, Ato Kidane Assefa, there is a joint committee recently formed between Hydrology and Water Quality Directorate and Meteorology Agency to discuss and agree on joint activities (selection of meteorological stations in the relevant catchment, resources sharing, staff exchange and joint research). This coordination is favourable to the quality of the overall monitoring.

Phase I: A general observation is that staff gauges are working properly, while automatic water level recorders are not functional (silt problem of intake chamber, chart shortage, lack of battery, old age of instruments etc).

Comment: Staff gauges are often damaged or gone, and a temporary scale is in some cases painted on bridge piers. It is important that damage is reported when it is noticed by the gauge reader so that the Hydrology and Water Quality Directorate can replace the gauge as soon as possible. The store of replacement gauges should never get empty. The time when the gauge was lost, as well as the time a new one is set up should be noted in the gauge reader’s book. The risk of damage to the gauge should be taken into consideration when a new gauge is set up. It may also be worth (for some essential stations) considering solid gauges design that will withstand the impacts of heavy debris at strong flow conditions. Examples of solid gauges are those implemented by the Egyptian Irrigation Department, in Egypt and Sudan.

Phase I: In most cases flow and sediment measurement have to be taken from bridges. Occasionally, this situation creates operational difficulties. Flow measurements of Abbay river at Kessie is very challenging as the bridge deck is elevated more than 20 meters above the water surface and the cable carrying the current meter will excessively deflect to result in inaccurate estimate of velocity. In such a situation Overhead-Cable-Car (OCC) system can be employed (similar to the non-functional OCC system that is available at Kessie).

Comment: A real attempt should be made to get the ADCP to function. The ADCP could be mounted on e. g. a trimaran type ‘boat’ dragged by a low cable. At the same time the possibility of using Surface Velocity Radar (SVR) need to be investigated. The location of the non-functional OCC is no longer a suitable discharge cross section, since the cross section was modified during the construction of the Kessie Bridge.

Phase I: Siltation rates for a large number of rivers is from moderate to high resulting in shifting rating curves for affected gauging stations have to be regularly updated by current metering (Rib river is an example, Abbay at Kessie)

Comment: At present there are too few measurements at each station to even detect the change in the rating curve. There are two alternatives:

a) Available budget is adapted to the monitoring needs

b) The monitoring efforts are adjusted to fit the available budget, by reducing the number of stations.

Apparently, at present the budget and resources are not sufficient for adequate monitoring at the large number of stations.

Phase I: Lack of discharge (current metering) measurements at high river stages is a problem for rating verification at a large number of stations (bridge platform based measurement often gives inaccurate result for large rivers)

Comment: Fully agree. This is where the use of ADCP or SVR will become a great leap forward. A real effort should be made to get the ADCP to function, and the possibility of SVR should be investigated.

Phase I: Motivation of observers is very poor, mainly due to very low salaries and practical difficulties in carrying out their work (silted and unreadable staff gauges, infrequency of supervisory visits etc). As a result there are often long series of missing or questionable measurements

Comments: Very true. To improve this situation will increase the costs of manual reading, thereby creating more incentive for installing and (not least) maintaining various types of automatic gauges. A proper evaluation is required to find the most reliable and user friendly type,

Phase I: There are valuable amount of older hard-copy data that has not been entered into the HYDATA database, and also requires proper archiving using secure steel cup boarded at appropriate space.

Comment: Some of this data has been found by project hydrologists and entered into project databases. It is important that:

a) All projects that collect, analyse, correct and elaborate on hydrometric data provides their database to the Hydrology and Water Quality Directorate.

b) The Hydrology and Water Quality Directorate makes sure this database is included under their own database in a way that makes it accessible, both for the Hydrology and Water Quality Directorate and for external users

5.2.2 Phase I Sudan

Phase I: The bottle neck of hydrological data monitoring in Sudan is the decline of both data quantity and quality during last few decades. This is attributed to fewer measurements, malfunctioning of equipment, and limited data validation.

Comment: It is worrying that there has been a decline. The same tendency can be seen in Ethiopia. If the reason was known it might be easier to do something about it.

Phase I: Provision of sufficient equipment for suspended sediment sampling, and (limited) equipment for bed load sampling, including grab sampling, depth integrated sampling, time-proportional composite sampling and space composite sampling.

Comment: Sampling of bed material for determining the grain size distribution is often neglected, although it provides a good opportunity to calculate the bed load. Bed load is very hard to measure at any reasonable accuracy, and is often assumed to be negligible compared to the suspended load. From a calculation the relative magnitude can be checked.

Phase I: Capacity building of the staff for field measurements, laboratory analysis, and the subsequent office work of data validation, storage and dissemination.

Comment: A good overall understanding of the monitoring task could be obtained by letting staff circulate from field work to laboratory to data processing and quality check – before they are assigned one specific duty.

Phase I: Proper coordination between all agencies working on sediment data monitoring, processing and publication [MoIWR (HRS, GWWD), EID, DIU, others] is important

Comment: This problem is particularly a Sudanese problem. Indeed good coordination and exchange of data is a necessity. A common database would facilitate coordination. A way forward could be to find a solution for Sudan on the coordination and internal sharing of data. Can this be solved in Sudan it would be possible to solve it anywhere, using a similar setup.

Phase I: Applied research work to support optimal sediment sampling and analysis, e.g., sediment budget analysis and the like.

Comment: Hydraulic and sediment transport modelling could also assist in the optimisation of sediment transport monitoring.

Phase I: Satellite imageries could be a potential source to assess trends of soil erosion.

Comment: Fully agree; see possible methodology in Annex 1.

Phase I: Bank erosion is a critical problem in the country, and has large economic implications. Therefore, a devoted research is needed at pilot sites, likely to be in the Blue Nile or Main Nile. The research comprises of dedicated field measurements of bank erosion, and morpho-dynamic modelling, perhaps also physical modelling to understand the process, and propose appropriate protective measures.

Comment: Morpho-dynamic modelling including 2D simulation including certain 3D effects such as helical flows, flexible mesh that allow the banks to shift by bank erosion has become a very powerful too. Physical movable bed models will not contribute much to the understanding, except in the case where the near field effects of some structural mitigation measures are under investigation.

5.2.3 Phase I Egypt

Phase I: The monitoring programs in Egypt made it clear that they had grown unreasonably broad - in other words: Today, the network monitors too many parameters at too many locations at different frequencies.

Comment: The monitoring system in Egypt is performed for different purposes, by the Environmental Agency EEAA for environmental monitoring, by Ministry of Health for drinking water quality, by National Water Research Center for other reasons. A data needs assessment is required to determine the monitoring network and the frequency of measurements. For a uniform system in the three countries a number of indicator parameters at a few selected stations are recommended.

5.3 Field Trips in Ethiopia

5.3.1 Introduction

Field trips were conducted to first the Abbay River basin in the period 21st to 25th July 2011, then the Tekeze River basin 5th to 9th August 2011, by the Hydrologist accompanied by Mr Solomon Kebede, Hydrologist at MoWE, Addis Ababa. A field trip was later conducted in Baro Akobo basin by the Water Quality specialist. Purposes of the field trips were:

a) Observe ongoing discharge and sediment measurements at some main monitoring stations of the main Abbay River
b) Review the conditions at a number of monitoring stations belonging to the MoWE in the three river basins.
c) Visit some of the monitoring stations in the Tana and Beles Integrated Water Resources Management Project micro-catchment areas, and meet people responsible for the monitoring and the database at the Bureau of Water Resources Development (BoWRD), Bahar Dar, and at the monitoring stations

d) Obtain a general impression of the conditions in parts of the soil-erosion prone areas of the river basins
e) Visit to monitoring stations belonging to University of Mekele located close to Mekele, operated in cooperation with University of Gent, Belgium.
f) Visit the branch MoWE branch office in Mekele.

As an addition to the programme, also one SCRP hydro-meteorological monitoring site 15 km off the main road near Danbacha was visited.

The MoWE is in the process of developing maps that show monitoring stations in each catchment, identified by a serial number. This number was in the following used to identify stations, although these numbers have to be used with care, as they are only unique within each catchment. Some, but not all stations also have a unique (and more complex) station ID. It is recommended that in future a numbering system with unique numbers is applied to each station is used, with no risk of any confusion in the identification of stations or mix of data.

During the field trip the organisation of the Hydrology and Water Quality Directorate at the MoWE as well of the present operations involved in the monitoring carried out by the MoWE were discussed. This was later followed up in meetings with Mr Alemayehu Tafesse, National ENTRO Coordinator and Ms Semounesh G. Seyom, Head of Hydrology and Water Quality Directorate, MoWE and her staff.

A meeting with the Hydrologist of NORPLAN, Dr Stephen Robinson, was held to obtain the views of an important user of the monitoring data from the MoWE. NORPLAN is the Consultant for the Mandaya and Beko Abo hydropower plants on the Abbay River.

5.3.2 Abbay River Basin

Day 1 (21 July 2011): Addis Ababa to Finote Selam

The station numbering used throughout this report is the one that the Hydrology and Water Quality Directorate is using in their station maps. In this system the number of a station is not unique in Ethiopia, so for proper identification, it should be used together with the name of the catchment. Stations are also identified by a (unique) station id.

The first station visited was Station 30 on the Sibulu River near Chancho. The station is located d/s an old road bridge with a new one a bit upstream. Staff gauges were in good condition (read twice daily) and the land-points for the cableway for discharge measurements were in reasonable condition. As per the common procedure at MoWR stations, cables and other equipment is not left at site, to minimize vandalism. Price cup-type current meter is used and depth integrated sampler (usual setup for MoWE stations). The monitoring station at Kessie Old Bridge, located downstream of the new Kessie Bridge, was visited. At the time of the visit (around noon) the monitoring team had left the site as the measurements had already been completed. We later met with Mr Gadamo, who is in charge of the monitoring at that station at the nearest village (Dejen). Like the station at Bure Bridge, this station is equipped with a Price AA current meter and a DN96 integrating sediment sampler, both procured from Rickley (US), under the on-going support from Norwegian NVE (financed by NORAD). The instruments and the rig used to lower them into the water from the bridge were inspected with the following observations:

- The rig appears inadequate (this impression was later confirmed after observing it in action at Bure Bridge)
- The current meter is damaged (hard to say from the observation if it would still give reliable results). Also the tail fin of the heavy torpedo shaped ballast load is damaged. It is uncertain if the tail will function satisfactory, in keeping the instrument in position.
- The sediment sampler is damaged. A collar meant to keep the intake nozzle in place is broken. Doubtful if the improvised repairs are sufficient to keep the intake in the right position. Also the one of the tail fins are broken off. It is uncertain if the tail will function satisfactory, in keeping the instrument in position.
- An ultrasonic water level gauge mounted on the bridge has stopped working (it was working initially). The instrument box is placed readily accessible at the bridge railings. There is, however, no vandalism at this station due to the guard posted at the landfall of the bridge.
- A float based water level recorder at a near-shore bridge pier is not functioning due to siltation. Water levels are read from staff gauges.
- The flow distribution at the station is not ideal, due to the effect of some fill material placed at the right bank upstream of the new Kessie Bridge in connection with bridge construction.
- There is an old and damaged cableway station upstream of the new Kessie Bridge (as described by Scott Wilson, 2008). There would be little point in rehabilitating the cableway unless a more uniform flow section is created (see above). At present it is believed measurements using ADCP is a better solution.

Mr Gedamu provided the following information about the monitoring and the equipment on site:

- Data collected is sent 3 times a year to Addis (flow, sediment, gauge books)
- NORAD through NVE finances replacement and repair of equipment
- A pressure cell is available for this station but presently in Addis
- There is no facility available for current meter calibration. Instead comparison is made with other current meter
- Mr Gadamo believes the damaged current meter functions well, after having carried out a spin test, with satisfactory result (in air)
- The inaccuracy involved in using one water level in the calculation of the discharge was discussed. This morning water level raised 20 cm from 9:30 to 11:00 (4.46 to 4.66)

Solomon Kebede informed about the use of ADCP at this site. It had not been possible to obtain any useful measurements. The ADCP had not been equipped with GPS. We also discussed the procedure of measurements and checks of the results carried out by the monitoring team during the measurements. As part of the normal procedure, the monitoring team will calculate the discharge and plot discharge and water level and compare it with the presently established rating curve. If the measured point is quite far from the curve (outlier), the reason has to be investigated and possibly the measurement repeated. This procedure has its pro's and con's. One the one hand it is positive that a check calculation of the discharge is done. On the other hand, using the fit to a rating curve as a measure of the success of the measurement, is unfortunate. It can be tempting to adjust measurements to arrive at a result close to the existing rating curve, to avoid redoing the measurement.

The monitoring station 58 on the Gudla River at Dembech was visited briefly. The station is located immediately downstream of the road bridge. Here it has been attempted to protect the cableway land-point on the right bank by building a steel plated shed around it, but attempts have been made to break this open. Staff gauges appear to be in order. Soon after station 58, the hydro-meteorological station belong to SCRP was visited. The station is located around 15 km North of the main road. It comprises a well-equipped meteorological station and float based water level recorder. The flow was low at the time, and we were informed that the catchment area was only 112 ha. This station was found to be kept in very good order. Mr Yigzaw, who took care of the monitoring and upkeep of the station, is very organized in his management of this station.

Also the monitoring station 59, Birr River near Jiga was visited. The station is located immediately downstream the road bridge which is an arch bridge from the Italian period. The station has a float based water level recorder locked in a steel shed, and also staff gauges. The land fixings for the cableway for discharge measurements seemed to be in order.

A last station visited on that day was station 62 river near Finoteselam. Also this station is located near the road bridge. Staff gauges seem in order. Discharge is measured from road bridge.

Day 2 (22 July 2011): Finote Selam to Bahar Dar

The first station visited on the second day was the station at Bure Bridge on the main Abbay. The monitoring team had not yet arrived but they came after a short while and we were able to observe a couple of velocity measurements. The setup was similar to that at Old Kessie Bridge. Mr Asfaw from Awash and Mr Gabriel from D. Markos were assisted by 4 helpers. Observations were as follows:

- From inspection prior to the measurements no visible defects were found, except that the tail of the torpedo shaped ballast was not mounted at the right angle. This was later corrected by the monitoring team, by hammering it with a rock
- It took about 1 hour before the current meter could be lifted over the bridge railing, the reason being the very impractical rig. The rig/crane is not at all made for the conditions at Bure and Kessie bridges, and not at all for such heavy ballast (which is necessary in the strong flow). After lifting the current meter off the ground, the rig needs to be tilted to get the current meter with ballast over the bridge railing. It took 5 men to tilt the rig while one was fully engaged in avoiding the current meter to get smashed against the bridge railing. This is a situation with high risk of damage to the instrument. The wheel s of the rig was about to lose its tires; these are not meant for this kind of loading. Heavy provisional ballast loading of the rig needed to be applied. A number of times the rig was getting unstable, a situation with a risk not only of damage to instruments but also of injury of staff
- A low cable across the river was meant to keep the current meter (and later the sediment sampler form drifting downstream with the current; this functioned well
- There was, however, a substantial lateral drift of the current meter, maybe due to inaccurate mounting of the tail fins of the ballast. It has to be mentioned that it takes a very small lateral force to get the instrument substantially out of position, due to the large length of cable

It was mentioned that damages usually occur during measurements close to the river bed, due to moving cobbles etc. This leads to considerations of whether it would be possible to leave out the measurement closest to the bed. The method of calculating the discharge based on fewer measurements would then need to be adjusted somewhat, compared to the standard WMO methods.

After arriving in Bahar Dar we met with the NIRAS Hydrologist for the Tana and Beles Integrated Water Resources Management Project, Mikaela Kruskopf, who took us to the Bureau of Water Resources Development (BoWRD), Bahar Dar, and were explaned about the HYDATA database of the project. We were also informed about the hydrological monitoring component of the project including the community participation etc. Also some discussions were held about the methodology to determine the discharges without measuring it.

Day 3 (23 July 2011): Bahar Dar to Debre Tabor

This day was dedicated to the visit to the monitoring stations in the Tana and Beles Integrated Water Resources Management Project micro-catchment areas. We visited a number of stations on small rivers in the upstream part, including a site for a potential new station, as well as sub-catchment stations further downstream. The downstream stations are managed by the MoWE whereas upstream stations are managed by the project.

The Station at Karara, Ribb tributary was visited. The station has a recording pressure gauge for water level records, as well as staff gauges and crest gauges to register maximum water levels. By means of two water level gauges it is the intention to calculate the discharge. The gauge readers also take water samples for secci turbidity tests. If the secci value indicates high concentrations a water sample is taken for determination of the sediment concentration.

A number of other stations were visited, and also a location in the upper Ribb catchment where a new station is planned (Baskura outlet).

Finally two downstream stations belonging to the MoWE were visited. The Ribb Station downstream of the Ribb Dam under construction is a flow station in good condition, with cableway land points, staff gauges, but also a float type water level recorder. The location, however, is not ideal, as this station is located immediately downstream of a sharp river bend.

Finally, the Lower Ribb station was visited. It is located by the main road bridge and was viewed from the bridge. The station has float type water level recorder and staff gauges. No cableway land-points could be seen from the bridge. Flow is measured from the bridge.

Day 4 (24 July 2011): Debre Tabor to Tenta

During this and the following day we drove through some areas commonly regarded as high erosion areas. Steep slopes are clearly a main factor. From what could be seen from a limited view of the area, the impression is as follows:

- terracing of the fields is not bad (better than expected)
- areas not terraced are usually those so steep that they have not been used for crops
- there is a lack of small and larger check dams to prevent initiation and progression of gully erosion

Two large gorges were crossed, the first the Chitta River gorge, the latter the gorge of the Bechelo River. Both valley bottoms are sediment filled. The Bechelo River is braiding at the bridge site as well as upstream, with shifting braid channels. This makes the cross section very difficult to use for monitoring. There may be a suitable section some distance downstream, but road connection is doubtful. The map shows a dirt road connection between Tenta and Shogave leading to Beshelo River further downstream; this might be an option, but was not investigated further. Very oblique flow at Beshelo Bridge has eroded the left abutment. No signs of any measuring station. We went back to the old bridge on the Dessie road. This bridge is not on the Bechelo River but on the Tria River, just upstream of the confluence with the Bechelo River. Staff gauges were installed here last season but have been washed away.

Day 5 (25 July 2011): Tenta to Addis Ababa

The first half of the day lead to high altitudes (>3600 m above sea level) driving along the watershed. Station 39 on the Jogola near Wereil was visited. The Jogola is a small tributary to the Welaka River. Cableway landpoints were found, but staff gauges had been washed away. We tried to get contact to the gauge reader but without luck.
As the gorges went to lower levels (around 1350 m above sea level), the climate appeared to be clearly drier.

Station 118 on Wenchit River at the road bridge was visited. Staff gauges had been washed away; no other signs of a monitoring station.

Station 47 on the Jemma River at the road bridge was visited. Also here there was no sign of a monitoring station, except that level markings had been made on the left bridge abutment.

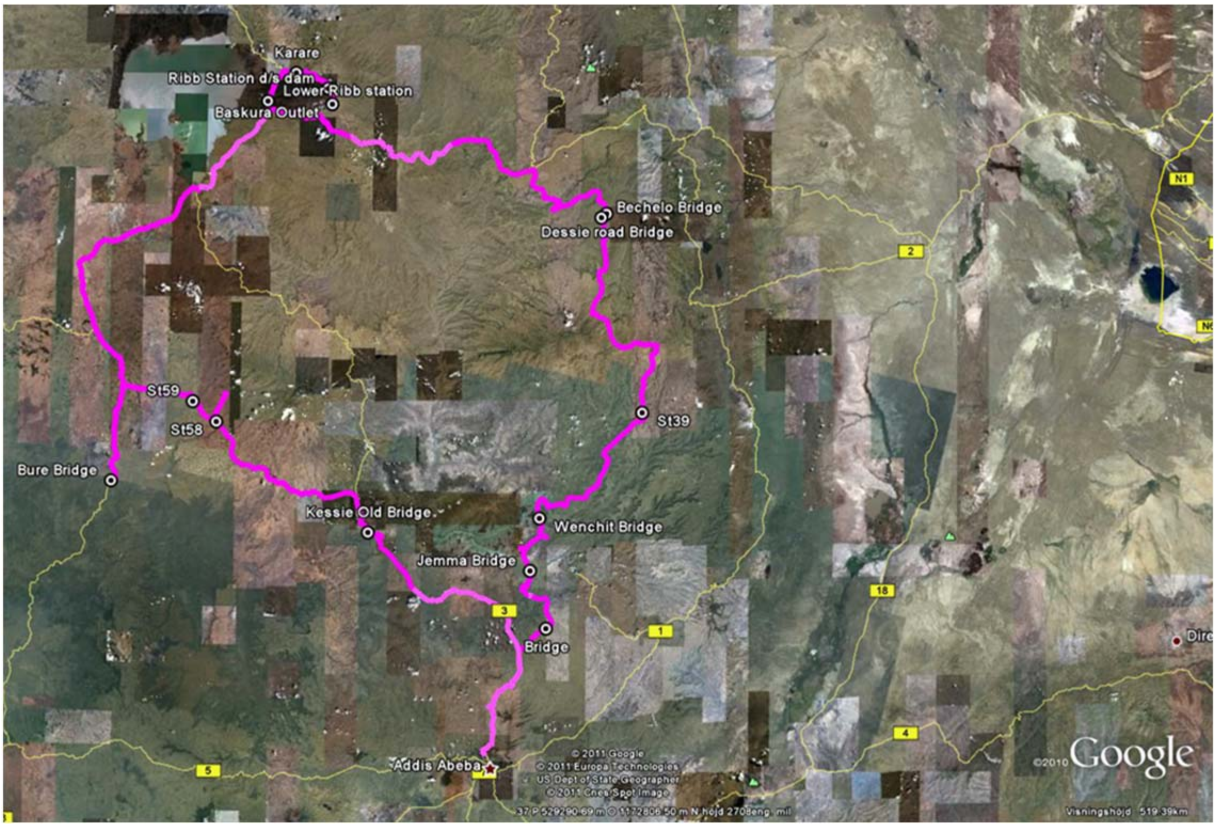


*Figure 2	Field trip route for the Abbay Basin field trip*

5.3.3 Tekeze River Basin

Station 3 on river Gheba near Mekel is located at a road bridge on a straight reach of a sandy river. Staff gauge and automatic water level recorder on left abutment structure. Water level recorder not working due to lack of paper. Signs of attempts to break into the box. Discharge measurements from road bridge. Control section less than 100 m d/s at present flow condition.

Station location is OK, but auto gauge should be serviced so it would function.

Station 4 on river Worie near Maike was not visited due to shortage of time. The station is located on the old road bridge, with access the large short distance along the old road (rough). The river was viewed from the new road bridge located downstream of the measuring section. Mixed sandy, rocky with gravel and blocks.

Station 5 on the main Tekeze River near Embam is located on a straight river reach with gravelly sand bars. The construction work for a new bridge immediately downstream has just begun. Elongated in-channel sand bar is dividing the flow in two, with a dominant right channel and very high flow velocities along the right abutment. The remains of the bridge structure that washed wash down by a flood in the 90'es is seen downstream of the bridge. A radar sensor water level recorder is mounted on the bridge, but is not working. Water levels read from staff gauges, we met the gauge reader. Flow measurements are presently not done at this station due to difficulties getting the instruments through gaps between bridge beams.

Measuring at this stretch of river is generally complicated by the shifting sand bars, that from time to time will divide the channel in two, maybe even three separate channels. It is doubtful if there are any more stable sections. Flow measurements close to the right abutment where velocities are very high will be difficult (had there been any attempt to do them). The problem arranging flow measurements due to narrow gaps between bridge beams is a problem that can be easily overcome by designing a cantilever type hoist device, especially made for this bridge (in fact similar type would facilitate measurements at other locations too). The new bridge, once it is completed, may or may not offer a better opportunity for flow measurement. A general advantage of using the old bridge, however, will be the reduced traffic, thereby better opportunity to work undisturbed.

Station 7 on river Gheba near Adi K is on a reasonably straight reach of a sandy river. No staff gauge, but levels marked in red paint on a bridge pier. Discharges are measured from the bridge. Minor stream joining immediately upstream of the right abutment. Control section at this particular flow, not far downstream of the bridge.

On the road between Stations 7 and 29 a small stream with large deposits of medium to coarse redish sand was crossed. The stream crosses the road in a culvert, which was half full of sand.

Station 29, Zamra River near Yechila is located on the road bridge at a river reach with sharp bends immediately upstream and steep slope causing very high flow velocities.

Staff gauge is located on a bridge pier, but this is not suitable due to high flow velocities. Discharge measurements are done from the bridge.

The bridge is not suitable as a measuring location. Following the river a few 100 metres upstream, past the bends, a reasonably straight reach with regular flow conditions was found. This location, which even has good access from the road, is far better suited for measurements. A small tributary immediately d/s this section still makes this section better suited than the bridge section.

Station 30, Tserare River near Sekota is at the road bridge. The river, which has gravelly bed, is braided with an island under the bridge. Also this location is unsuitable due to a complex cross section with high velocities. The water level gauge, placed on a bridge pier would usually give very misleading records. In fact, this is a “textbook example” of how NOT to place a water level gauge.

The two stations, 29 and 30 together give important information about the generated runoff of the combined Tserare catchment. An alternative to those two stations would be to look for one suitable location downstream of the confluence not far from the present stations. Road access is the critical parameter, but does not seem impossible as this area is quite populated, which means getting access may be a matter of improving existing access paths rather than make entirely new.

Examples were seen of good terracing and minor check dams, but also examples of progressing rill and gully erosion, usually in steep terrain with sparse vegetation, but even on vegetated slopes. Gabions are often used for these minor check dams and for slope protection. Some gabions have very thin wired steel ‘boxes’ and are not likely to last. The ones seen were newly constructed.

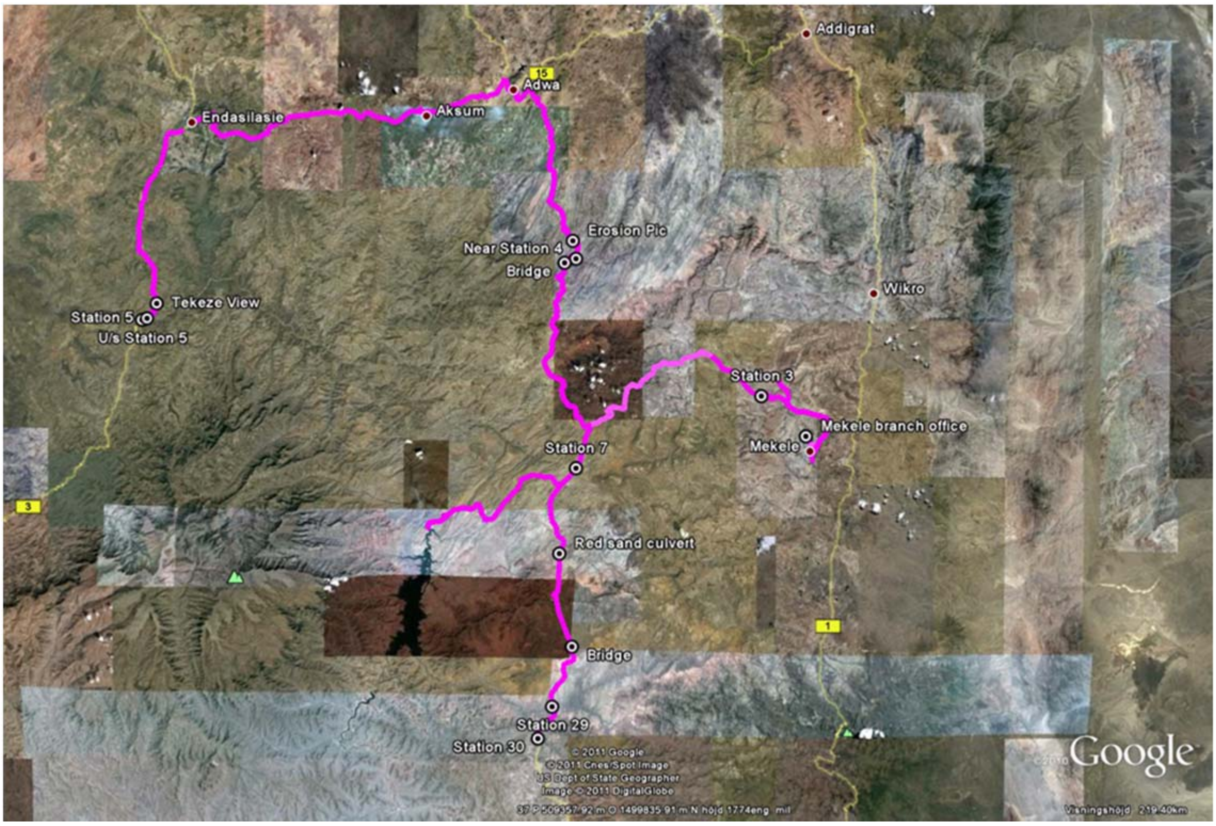


Figure 3 Field trip route for the Tekeze field trip

A monitoring station belonging to the University of Mekele, located close to Mekele was visited, where sediment as well as flow and water levels are measured. The station is on a small flashy river and measuring high flows is impossible. Damage occurs frequently and the station we saw did not have a staff gauge.

The MoWE branch office in Mekele was visited. The office, which is located at the premises of the Department of Meteorology, has no one responsible at the moment. An indoor store room could not be opened. A rig for current meter measurements (like the ones at Kessie and Bure, except this one was not modified for heavy loads) was found lying outdoors, along with a locally made rig.

5.4 Field trips in Sudan

Field trips in Sudan were carried out during the periods 14-15 September 2011 and 29 November to 2 December 2011. The visits were made possible through the kind assistance of the national focal points, in spite of the present difficult situation in the Nile Basin cooperation.

Several meetings were held, both in Khartoum and in Wad Madheni. Key persons met are:

- Eng. Ibrahim Adam Ahmed ENSAP Watershed Management Project, National Coordinator
- Dr Salih Hamad Hamid, NBI/WRPMP/DSS-Unit Sudan, National DSS Specialist
- Mr. Musa Mustafa Designation: Deputy Director, Dams Directorate, Ministry of Irrigation & Water Resources
- Dr Ahmed El Tayeb Ahmed, DG General Directorate Technical Studies, DIU
- Eng Abdelrahman Elzein Saghayroon, Dir Water Harvesting Directorate, DIU
- Prof. Dr Abdalla Abdelsalam Ahmed, Director General UNESCO Chair.
- Prof. Ahmed Salih UNESCO Chair in Water Resources
- Eng Ms Vidad, Nile Water Directorate
- Mr Redwan Abdelrahman, Chief Surveyor, Ministry of Irrigation & Water Resources
- Professor Seif Eldin Hamad Abdalla, DG HRS
- Ass Prof, Abu Obeida Babiker Ahmed, Head, Hydraulics and Water Resources Research Unit (Acting DG), HRS
- Dr Yasir Mohammed, Phase I consutant and advisor to HRS

The meetings gave a good impression of the prevailing conditions regarding monitoring and data storage in Sudan. The information received confirmed the findings of the Phase I Consultant, but added some further details to it.

The number of hydrologic and sediment stations in the Nile Basin in Sudan is far less than in Ethiopia. Table 1 gives an overview of existing stations, with key stations marked in yellow.

Table 1a Monitoring stations on Blue Nile and Main Nile (key stations highlighted)

Blue Nile

No	Station	Erection	Coordinate		Zero gauge	gauge	Discharge	ID
1	El deim		E 31.94	N 11.26	481,20	HH	Q	900011
2	Old Roseires	1905	E 34.38	N 11.85	429,21	HH		900042
3	Roseires (U/s)	1966	E 34.38	N 11.95	3,00	HH		0900021
4	Roseires (D/s)	1966	E 34.39	N 11.83	3,00	HH	Q	0900031
5	Sinnar ((U/s)	1925	E 33.63	N 13.55	403,00	HH		0900061
6	Sinnar ((D/s)	1921	E 33.64	N 13.55	403,00	HH	Q	0900071
7	Wad Elhdad	1907	E 33.58	N 13.79	392,17	HH		0900091
8	Hag Abdulla	1910	E 33.58	N 13.94	390,22	HH		0900101
9	Wad Medani	1911	E 34.62	N 13.40	405,09	HH		0900121
10	El Kamleen	1906	E 33.18	N 15.08	371,61	HH		0900131
11	Wad Aleis	1922	E 34.00	N 13.00	410,76	HH	Q	0900052
12	Khartoum	1904	E 32.52	N 15.60	363,00	HH	Q	0900152

Main Nile

No	Station	Erection	Coordinate		Zero gauge	gauge	Discharge	ID
1	Tamaniat	1921	E 32.56	N 15.98	358,73	HH	Q	1100012
2	Shendi	1913	E 33.43	N 16.70	342,46	HH		1100031
3	Hudeiba	1906	E 33.92	N 17.56	331,43	HH		
4	Hasanab	1945	E 33.97	N 17.65	332,29	HH	Q	1100042
5	Atbara	1907	E 33.97	N 17.68	332,82	HH		1100051
6	Abeidyh		E 33.92	N 18.27		HH		
7	Shereik		E 33.57	N 18.78		HH		
8	Dagash	1974	E 33.42	N 19.33	298,60	HH		1100062
9	Abu hamad		E 33.32	N 19.53	298,33	HH		
10	Merowe	1906	E 31.81	N 18.48	231,30	HH		
11	El Daba				217,36	HH		
12	Dongola	1962	E 30.49	N 19.18	212,03	HH	Q	1100092
13	Barbar	2007	E 33.99	N 17.99	337,05	HH	Q	
14	El Trfaya	2007	E 33.56	N 18.76		HH		
15	El Housh	2006	E 32.04	N 18.64	243,91	HH		
16	El Hesai	2007	E 32.01	N 18.589	238,47	HH	Q	
17	Abu Seliem	2007	E 32.02	N 18.62	237,43	HH		
18	Bagaria	2007	E 32.02	N 18.064	242,46	HH		
19	Merowe (U/s)				242,46	HH		
20	Merowe (D/s)				260,46	HH	Q	
21	El Taabya	2007	E 32.69	N 16.33	340,22	HH	Q	
22	El Misketab	2007	E 32.69	N 16.34	347,88	HH	Q	
23	El HUGNA	2007	E 32.68	N 16.35	354,13	HH	Q	
24	Sabu	2007	E 30.55	N 19.95	196,09	HH	Q	
25	Keddain	2007	E 30.59	N 20.05	193,74	HH		
26	Koro	2004	E 33.38	N 19.40	305,68	HH	Q	
27	El Gwabra	2008	E 33.15	N 19.19	291,00	HH	Q	
28	El Dalta	2008	E 33.33	N 19.19	306,11	HH	Q	
29	Dal	1969	E 30.57	N 20.97	158,79	HH		
30	Argo	1923	E 30.45	N 19.42	205,36	HH		

Table 1b Monitoring stations on White Nile, Upper Atbara, Dinder and Rahad (key stations highlighted)

White Nile

No	Station	Erection	Coordinate		Zero gauge	gauge	Discharge	ID
1	Malakal	1906	E 31.67	N 9.55	375,19	HH	Q	0800092
2	Jebal Aulia(u/s)	1933	E 32.50	N 15.22	355,32	HH		0800221
3	Jebal Aulia(D/s)	1937	E 32.50	N 15.22	355,32	HH	Q	0800231
4	Rabak	1921	E 32.70	N 13.17	366,72	HH		
5	Mogran	1916	E 32.52	N 15.62	362,70	HH		0800251

Upper Atbara

No	Station	Erection	Coordinate		Zero gauge	gauge	Discharge	ID
1	Wad Elheliew	1966	E 35.99	N 14.23	478,48	HH	Q	10001012
2	Kubur	1966	E 36.00	N 14.08	470,54	HH	Q	1000012
3	Old Girba	1906	E 35.92	N 15.00	422,50	HH		1000041
4	Girba(u/s)		E 35.92	N 15.00		HH		1000021
5	Girba(d/s)		E 35.92	N 15.00		HH	Q	1000031
6	El Showak		E 35.47	N 14.23	455,89	HH		1000072
7	El Sofi	2007	E 35.91	N 14.20	471,61	HH	Q	
8	El Rumela	2007			476,20	HH	Q	
9	Brdana	2007			483,81	HH	Q	
10	Atbara (K3)	1923	E 34.00	N 17.68	334,33	HH	Q	1000052

Dinder and Rahad

No	Station	Erection	Coordinate		Zero gauge	gauge	Discharge	ID
1	El Guisi		E 34.10	N 13.32	404,64	HH	Q	
2	El Hawata		E 34.62	N 13.40	418,48	HH	Q	

The Consultant visited Merowe Dam, Wad Madeni and the two Khartoum stations on the Blue Nile. On the Khartoum visit Mr Redwan Abdelrahman accompanied and gave an impression of the gauging at some of the stations. Mr Redwan could further inform about the measurements being carried out by the Ministry.

It is characteristic for Sudan, and a special challenge in coordination, that several different institutions are doing each their part of the monitoring. Most stations are monitored by MoIWR; some belong to the Egyptian Irrigation Department (EID) and some to the Dams Implementation Unit (DIU). Some sediment measurements and all sediment analyses are done by HRS in Wad Madheni. All Nile Basin monitoring data are sent to the Nile Water Directorate under MoIWR. Monitoring of non-Nile rivers belong under the Ground Water and Wadis Directorate (under MoIWR) as does some water quality measurements in the Nile.

Like in Ethiopia, there has been a decline in discharge measurements during latest decades. A comprehensive explanation of this problem has not been found.

The use of new techniques has been initiated. ADCP has been and is used extensively by DIU, where their 3 instruments are in good working condition. Also MoIWR has 3 instruments; however, none of these are working. Two of the ADCPs belonging to MoIWR were inspected, as they were lying idle with the MoIWR:

All 3 instruments are 1200 kHz – which is not the appropriate type for the high sediment concentrations often experienced in the Nile in Sudan. These instruments will not work in high sediment concentrations, which were also found by MoIWR. The trimaran type boat has only one hole available for mounting of the ADCP, which means they are not suitable for adding the GPS and echo-sounder likely to be required in high sediment movable bed conditions. The faults of the two instruments were partly internal electronic faults, partly torn cables. It is not possible to make any repairs in Sudan.

Figure 4 Faulty ADCP and field computer belonging to MoIWR

Figure 5 Trimaran type 'boat' for mounting of the ADCP (MoIWR)

The problem with the use of high frequency ADCPs under high sediment concentrations was investigated in Sudan 2007 by Water Survey of Canada for Capacity Building for Nile

Basin Water Resource Management (Woodward, 2007). It was then realized that a lower frequency of 600 kHz should be used. This is the instrument that DIU is now using with success.

MoIWR does have one echo-sounder, but it is only used to measure the bathymetry of the Roseries Reservoir, not for river cross sections. According to Mr Redwan, cross sections are generally stable, except in Blue Nile stations and Atbara stations. It is not unexpected that this is the case, and the fact that it has been noted that cross sections are not stable in these rivers, means that river cross sections should be measured regularly at these stations.

A very positive development in Sudan is the extensive survey being done by French IGN mapping by LIDAR technique the shores of the Nile, and the corresponding hydrographic surveys of river cross sections. This will make it possible to obtain a good vertical control and – hopefully – relate the various historical measurements that have been done to different reference levels.

As also found by the Phase I Consultant, the DIU has made the best progress with the application of new advanced techniques. They have been assisted by for instance DHI Water &Environment (Denmark) in setting up a methodology for applying the ADCP at Merowe Dam. A practical difficulty they (and also MoIWR) are facing is the import embargo imposed on Sudan, which hits the import of advanced electronic equipment.

Figure 6 Staff gauge at Khartoum Gauging station at Sobat Bridge (West bank). Oblique gauge and large level gap between gauges

5.5 Field Trips in Egypt

A visit to Egypt was conducted by the Water Quality Expert, but no field trip with focus on sediment monitoring was done in Egypt. The reason is that all sediment arriving to Egypt from upstream in the Nile, will deposit in the Lake Nasser/Nubia. Any sediment related issues in Egypt, downstream of Lake Nasser/Nubia, are therefore unrelated to sediment processes outside the Egyptian borders.

The sedimentation I Lake Nasser/Nubia originates from the Nile, in combination with a smaller contribution from wind-blown sand. These subjects are discussed further in sections 5.6 and 5.7 below.

5.6 Lake Nasser/Nubia Sedimentation Monitoring

The continually ongoing process of sedimentation of the Lake Nasser/Nubia will eventually affect the regulation of the flow of the Nile downstream of Aswan High Dam (AHD). The sedimentation of the Lake Nasser/Nubia, therefore is an issue of national concern in Egypt.

The monitoring of this sedimentation makes it possible to better understand the process and to detect any changes in the rate of sedimentation. It may be possible to relate changes to natural processes or human interferences in the upstream river catchments, thereby creating a basis for influencing such natural processes or upstream human behaviour.

The monitoring further provides the possibility of influencing the deposition pattern in future through a variety of measures:

- influencing the inflow of water and sediment to the Lake from the Nile

- dredging of sediment or influencing sedimentation through structural measures

- changing the regulation of the water level of the Lake

At present, sedimentation is very limited in the Egyptian part of the Lake as by far the most sedimentation takes place in the Sudanese part. Sedimentation is not a concern in Sudan. On the contrary, here the sedimentation is considered as positive for the local population, as the new land created by the sediment deposition becomes valuable agricultural land. In Sudan, there are presently no plans to try to influence the natural process of sedimentation in any way – but in fact the new Merowe dam, now in operation is going to reduce this sedimentation. In Egypt, such plans are quite developed, but the options of implementing such plans are at present virtually non-existing, as the sediment is found in relatively small amounts and mostly in relatively large water depth from where it would be quite costly to dredge it.

Monitoring of the sedimentation of Lake Nasser/Nubia has been going on for decades, but it is considered necessary to improve the accuracy of the monitoring in order that the generated information can be utilised. The improved monitoring system is well justified, provided the information and knowledge established is utilised to influence human activities affecting the sedimentation.

The planned Lake Nasser/Nubia monitoring (SWECO, 2007) consists of:

Lake bed bathymetry (including dry shore)(see also Annex 2, in particular Chapter 9)

- Multi-beam echo sounder for bathymetric surveys
- LIDAR green and red light bathymetry/topography methods for bathymetry (in areas of clear water, e g at low inflow/shallow water)
- bed penetrating sonar, to test the possibility of detecting annual layering

Grain size distribution and sediment quality of bed sediment

- acoustic sub-bottom profiler (single or multi-beam)
- submerged penetrometer
- sub-surface sampling techniques

Wind measurements

- wind gauging station(s) (continuous)

Flow/discharge and water levels

- Acoustic Doppler Current Profiler (ADCP) (minimum 2 for vessel mounting and minimum 1 for placing on lake bed)
- Water level recorders

Temperature

- survey of density stratification (echo-sounder or ADCP)

Sediment concentrations

- ADCP (backscatter signal calibrated against measurements)

The expected outcomes are:

1. Functioning Monitoring System comprising:

a. Optimised plan and procedures for surveys and measurements

b. Accurate and efficient survey equipment to suit the data need

c. A suite of mathematical models set up to satisfy existing and possible future requirements

d. A flexible and expandable database to contain essential data from the surveys and measurements and awareness with potential users

e. Guidelines and user-level training to potential users of the database

f. Well trained staff to operate and maintain all components of the Monitoring System

2. Results from the study of sand encroachment and mitigation measures comprising:

a. A procedure based on satellite images and GIS for assessing the problem of sand encroachment and river bank erosion

b. Quantifications of wind-blown sediment volumes into the Lake and into the Nile up to Merowe Dam

c. Prioritised list of areas where sand encroachment is a problem

d. Recommendations of mitigation measures

5.7 Wind-Blown Sediment and Sand Encroachment

Wind-blown sediment may settle within the river cross section (encroachment), in reservoirs or it may cause destruction of settlements and agricultural areas. This is a problem in Northern Sudan along the Main Nile and wind-blown sand is considered a significant contributor to the sedimentation of Lake Nasser/Nubia. The encroachment on the Nile upstream of the Lake may even have unfavourable effects on the river morphology. Sand/silt material that enters the river cross section may cause a partial blocking effect of the Nile until the flow of the Nile is strong enough to remove the sediment supplied by the wind.

All of these phenomena have been studied, but a quantitative evaluation of the consequences and the volumes of sand involved still remain.

Under the Watershed Management Fast Track Project, Egypt-Sudan preparation (SWECO, 2007), a project component was defined with the aim of quantifying the wind-blown sand and at the same time it pointing out target areas for mitigation activities. Monitoring under this project would include wind measurement, remote sensing analyses to track dune movement, sand encroachment and bank erosion. Finally, morphological mathematical modelling would be used to determine the morphological impacts of sand encroachments on the river Nile. Sufficient wind monitoring stations would be needed to satisfactory map the wind conditions within the area being studied. The project will make its own assessments, based on available information. In addition, the project will plan and set up activities to quantify the sand encroachment on the Nile between Merowe dam and the Lake more accurately.

Satellite imagery is an important tool in the assessment of sand encroachment problems. Partly because it is possible from the satellite images to map the areas covered by wind-blown sand, and divide this into different categories. Partly, it is possible to detect any changes over a certain period of time, including the migration of sand dunes. In order to assess the sand volumes involved in dune migration it is necessary to know the dune dimensions, which means satellite images need to be coupled to a terrain model established from remote sensing data or field surveys.

The activity would make use of acquired satellite images, combined with ground-truthing and certain field surveys.

The project will apply the latest available technology in remote sensing and GIS, and combine this with theoretical research in the physics of wind-blown sand and dunes, as well as the more practical experiences involved in designing appropriate mitigation measures.

This project is presently under implementation, but its present status is not known.

5.8 Follow-Up Investigations on Modern Flow Measurement Methods

Observations made during the field trips and ideas arising out of interviews and conversations with officials, consultants and ENTRO staff were followed up in further meetings and collection of additional information from various sources.

5.8.1 Investigations on the use of ADCP in rivers of high sediment concentrations

Scott Wilson (2008) had mentioned but discarded the use of ADCP for flow measurements in the main Abbay stations, with reference to problems with such measurements at high sediment concentrations in the Nile at Khartoum 2006. No reference to these measurements were provided by Scott Wilson, but through internet search some information was found on these measurements, including information that further tests would be conducted 2007. Also contact details to the Canadian consultant in charge of the measurements, Mr Jeff Woodward from Environment Canada. He informed that the problem had been due to movable bed, which made it impossible to use the bottom tracking, and provided his field trip report. After some tests with adding GPS to the setup, the problem had been solved.

Contacts to RD Instruments also confirm that their River Ray setup could be adapted to cope with situations with high sediment concentrations. High frequency instruments have poor penetration in high sediment concentrations, which means a 600 kHz ADCP should be chosen rather than 1200 kHz. They use a broad frequency band, which should also improve the results.

Initial contacts to NVE (Norway) indicate that the ADCP used was indeed a 600 kHz ADCP (Rio Grande Work Horse). The understanding of why the attempts to use the ADCP in heavy sediment laden rivers of Ethiopia failed, while this was possible in Sudan, is the key to overcoming the obstacle of using ADCP in Ethiopia.

Based on own experiences from the use of ADCP to even measure sediment concentrations in sediment laden rivers in Bangladesh (after proper calibration against conventional sampling), this question has been raised with both Mr Jeff Woodward and RD Instruments. Their responses are very promising and should be followed up.

The ‘boat’ used to mount the ADCP is very important. With difficult rapid flow conditions it should move smoothly in the water and be prepared for mounting of not only the ADCP but also GPS and echo-sounder. The following clips from another supplier (Sontek) illustrate well both the principle and how the boat behaves in rapidly flowing water.

http://www.youtube.com/watch?v=KDLUAi3tal8

http://www.youtube.com/watch?v=JVa01yF-cgs

The possibility of using the ADCP to measure suspended sediment concentrations is an important advantage of the ADCP over the Surface Velocity Radar (SVR) methods described briefly in the following section. But there are a number of questions to be investigated:

- Will the ADCP function with bottom-tracking, even in high sediment load? This would mean it can be used in its standard setup, without adding DGPS. This is doubtful but if a limit is established the ‘simple’ standard setup can be used in rivers with less sediment.
- If bottom tracking does not work, will the ADCP be able to detect the bottom or will the signal reflect from the high-concentration moving sediment layer above the bottom – in which case an echo-sounder needs to be added.
- Will a GPS have sufficient satellite contact in the deep gorges? Handheld GPS had no problems during the field trip, but the accuracy was not noted.
- Will the Bluetooth communication to shore (standard with the River Ray from RD Instruments) be sufficient or will another type of radio link need to be used?

Depending on the answers to these questions the cost of the complete ADCP setup will be 25,000 USD to 50,000 USD.

5.8.2 Investigations on the use of Surface Velocity Radar (SVR)

Given the large challenges of measuring river discharges with current meters lowered into the rapidly flowing water with large solid particles and debris that frequently damage and destroy the equipment, it is tempting to think of non-contact methods.

Emerging new technologies apply non-contact methods to measure first of all the surface flow velocities at a cross section, but even the cross section profile. Field tests have been going on for more than a decade and the present status will be investigated further.

The USGS has reported on a number of successful tests, for instance Haeni et al (1999) and Costa et al (2005). Surface velocities are measured by radar mounted on the bridge or on a car standing on the bridge. A ground penetrating radar mounted on a light cableway records the river cross section. Flow profiles are theoretically calculated before the calculation of the total discharge. The reported accuracy is very good.

The SVR methods are based on the Doppler principle. Thus, for this method to work, the object of the measurement (in this case a water surface) should be moving towards or away from the measuring instrument during the measurement.

Hand-held Surface Velocity Radar “pistols” have been found commercially available. Further investigations should be conducted to determine if more advanced and suitable equipment (e g with automatic position control) is commercially available.

6 Main Findings

The following are the main findings from field visits and discussions with managers, experts and monitoring staff in Ethiopia and Sudan, as well as international consultants and instrument suppliers. As the investigations in Ethiopia were more intensive than in Sudan, findings are more detailed for the case of Ethiopia.

Findings for Egypt are based on the Consultants knowledge from his previous assignment for the Watershed Management Fast Track Project for Egypt-Sudan (SWECO, 2007).

The reviews of the Phase I reports and discussions with the Phase I Consultants for the three countries were taken into account.

6.1 Monitoring Needs and Objectives

Whereas the need for hydrological and sediment monitoring is very obvious in all countries, the objectives are not well understood, defined or detailed. This is perhaps the most serious deficiency in the monitoring networks in the three countries. Without defined objectives, it is not possible to set up detailed requirements to separate components of the monitoring system, and not possible to check if data are sufficient or not.

This means that a new design of the monitoring network will have to start with establishing a design basis, meaning it has to start with answering questions like:

1. What are the purposes of the monitoring?
2. What information is needed from each river/tributary (may vary)?
3. With which frequency is this information needed during different seasons?
4. With which accuracy?
5. How urgent is it needed? (real time or allow for transfer and processing)

The specifications for the monitoring network would be based on the answers to such questions.

Due to this lack of defined objectives, the Consultant has drafted his own objectives for a future monitoring system in the three countries. As mentioned earlier, there has been less focus on Egypt, so here the objective is focused on the Lake Nasser/Nubia.

6.1.1 Ethiopia

The discharge of the Nile is predominantly generated in the Ethiopian highland. The steep slopes of the deep valleys are also the main source of sediment transport in the Nile. At present, high flows generated by the Ethiopian runoff is creating flood problems downstream. Also the high sediment load generated by soil erosion in the Ethiopian highland is creating numerous problems further downstream, such as sediment deposition in reservoirs and irrigation canals. Naturally, the soil erosion in the Ethiopian highlands is in itself a problem, as valuable agricultural land is lost.

Until recently Ethiopia had very few water storage reservoirs and very limited irrigation development. But recently, a number of large dams have been constructed and even more are on the way. These will have considerable impact on the variability of river flow downstream and will reduce the amount of sediment that is transported downstream.

Suggested objectives of hydrological and sediment monitoring in Ethiopia are:

- Identify river branches with high sediment concentrations, thereby contribute to the identification of soil erosion areas, in order that soil conservation activities can be focused on the erosion hot-spots.
- Provide a reliable data basis for feasibility and design studies for any project that rely on or is affected by the river flow or sediment transport, such as irrigation and development of new reservoirs
- Check of the inflow of sediment to existing reservoirs from upstream measuring station (to be compared with directly measured bed level changes in the reservoir)
- Monitor the changes in the flow and sediment transport as these are being increasingly affected by upstream regulations, and by climate changes
- Bathymetric surveys of reservoirs for operation and maintenance planning

6.1.2 Sudan

The river flow of Nile rivers through Sudan is predominantly generated upstream in Ethiopia. This does not mean that runoff from local rainfall within Sudan can be totally neglected, but its contribution to the annual discharge is relatively insignificant. When it comes to sediment transport it is mainly Eastern Nile Rivers (particularly Blue Nile and Atbara) that contribute to sediment transport through the rivers of Sudan. Also the sediment transport in these rivers is predominantly generated outside the Sudanese borders, in Ethiopia. This means that Sudan has no direct control over the main sources of the water and sediment that is flowing in the river Nile.

Sudan is economically dependent on the Nile, as a water source for water supply and irrigation and as a source for power generation. The high variability of flows and water levels has historically been the basis of flood irrigation, whereas excessive floods cause destruction and economic losses, directly through flooding of homesteads and infrastructure or indirectly as consequences of river bank erosion. Similarly, the high silt content of Eastern Nile rivers brings good soils to the farmers during floods, but it is also a major problem as it causes storage loss of reservoirs and siltation in irrigation canals and thereby causes huge costs of maintenance.

The variability of river flow is natural, but subject to change through regulation. Like the complete Nile flow regulation in Egypt, achieved by the Aswan High Dam, all reservoirs established on the rivers contribute to the regulation of the flow. New or heightened dams will further regulate the flow and influence the sediment transport by trapping a large fraction of the sediment entering the reservoirs (Merowe, Upper Atbara and Roseries heightening). After a major regulation, a river changes its character. Some changes are immediate (flow) and some take a long time to fully develop. The morphological characteristics of a river change, when it is regulated and when it is deprived of the amounts of sediment it used to receive from upstream. It will very slowly change its morphological characteristics, through erosion/deposition of sediments that will shift river channels and with time cause additional problems such as erosion further and further downstream. Reaching a new dynamic equilibrium may easily take decades, if not a century.

For the sake of completeness, Sudan is also affected by the Lake Nasser/Nubia, since part of the reservoir and the Nile affected by the reservoir through backwater effects, is in Sudan. As a result, silt is presently accumulating in a new formed ‘delta’, providing fertile agricultural land.

Major ongoing developments upstream in Ethiopia is also going to impact Sudan. New major dams on the Blue Nile and even dams on other rivers will have major downstream impacts.
The mainly favourable impacts are:

- Regulation of the flow
- Reduced sediment inflow

Possible unfavourable impacts are:

- Risk of flooding due to dam breach
- Erosion damage due to reduced sediment inflow

Unique to few rivers in the world, the sediment load of the main Nile is also contributed to by sand blown by winds from neighbouring lands. Limited research efforts attempted to quantify the increment in sediment load, and the associated morphological implications of sand encroachment. Mostly the research in this area, concentrate on loss of agricultural land and houses near the river, and the desertification effects rather than the possible morphological changes.

Based on the above description, continuous monitoring is required and will be of great benefit in the further development of the country's resources. It is also clear that many old data will soon be of very little use, as they belong to a river of different characteristics, due to regulations being implemented, and possibly even due to climate changes. They can of course be useful in the analysis of determining the impacts of for instance dam developments in Ethiopia and Sudan.

Suggested objectives of hydrological and sediment monitoring in Sudan are:

- Provide a reliable data basis for feasibility and design studies for any project that rely on or is affected by the river flow or sediment transport, such as irrigation and development of new reservoirs
- Check of the inflow of sediment to existing reservoirs from upstream measuring station (to be compared with directly measured bed level changes in the reservoir)
- Monitor the changes in the flow and sediment transport as these are being increasingly affected by upstream regulations, and by climate changes
- Bathymetric surveys of reservoirs for operation and maintenance planning
- Monitoring of sand encroachment, to be able to quantify it and assess the impact it has on the Nile in Northern Sudan.
- Monitor bank erosion from remote sensing data.

6.1.3 Egypt

The High Aswan Dam and Lake Nasser/Nubia provides complete regulation of the flow of the Nile in Egypt, thereby preventing floods and droughts, which would have a devastating effect on the whole country. Lake Nasser/Nubia is at the same time by far the most important water source of Egypt and a very important source of hydroelectric power. The importance of Lake Nasser/Nubia as a flow regulating reservoir and a fresh water source cannot be overestimated.

As a fresh water source it is important that the water quality of the stored water remains high. This aspect is treated by the Water Quality Specialist.

The main function of the reservoir, as regulator of the flow of the Nile, is threatened only by the sedimentation of the reservoir. Sedimentation reduces the live reservoir volume and thereby the regulating capacity of the reservoir.

This was the background, when the Fast Track Project for Egypt-Sudan was initiated by ENTRO in 2006. The consultant for the programming study wrote in their report the objectives of improved Monitoring System for Lake Nasser/Nubia (SWECO, 2007):

The project shall:

- Establish a strong tool to guide decision makers in the controlled future development around Lake Nasser/Nubia. The tool will be applied under the Lake Nasser/Nubia Management Framework (LNNMF), which is presently being developed.
- Establish a Monitoring System to monitor and analyse the development in important physical characteristics that affect the sedimentation of and water quality in the Lake Nasser/Nubia.
- Quantify the volume of sediment entering the Lake and identify and prioritise areas along the river Nile between Merowe Dam and the Lake, that are exposed to serious consequences due to encroachment by wind-blown sediment.

6.2 Organisation of Monitoring

6.2.1 Ethiopia

Monitoring of the Ethiopian rivers is presently done by the Hydrology and Water Quality Directorate under the MoWE. The Phase I Consultant (Ethiopia) has recommended that it remains like that. The present Consultant recommends a close coordination of the hydrometric and related meteorological monitoring. It has been learned that some coordination is already taking place, guided by a joint committee between Meteorology Department and Hydrology and Water Quality Directorate. In a longer perspective it should even be considered to place the Hydrology and Water Quality Directorate under the Department of Meteorology, which is under the same Ministry. The reason is the following:

In the hopefully not too distant future, mathematical models will be set up to simulate the hydrology (water levels and discharges), the sediment transport and even soil erosion. These models will be used for forecasting and for planning purposes. Input data include precipitation data as well as discharge data and even sediment transport data, in the case of sediment transport modeling. The model therefore links the meteorological and the hydrometric data. Because of that it is convenient to place the Hydrology and Water Quality Directorate under the Department of Meteorology.

This option needs to be discussed and investigated further.

River Basin Authorities (RBA) are being established in accordance with a main principle of the Water Sector Development Programme, 2002. Once established, it is recommended that the field monitoring and a large part of the data processing and laboratory testing is done by the RBAs. It is important, however, that the overall responsibility for the monitoring, the coordination and the final QA and databases remains the responsibility of the Hydrology and Water Quality Directorate.

6.2.2 Sudan

In Sudan, the responsibilities for monitoring is scattered amongst numerous different organizations, which is a particular challenge in the case of Sudan. A focal point, at present, is the Nile Water Directorate (NWD) under the MoIWR. Data from all data collecting agencies are said to be collected at the NWD. The Most stations are monitored by MoIWR; some belong to the Egyptian Irrigation Department (EID) and some to the Dams Implementation Unit (DIU). Some sediment measurements and all sediment analyses are done by HRS in Wad Madheni. Monitoring of non-Nile rivers belong under the Ground Water and Wadis Directorate (under MoIWR) as does some water quality measurements in the Nile. According to the Phase I Consultant, there is no unified database (or dataset) of sediment measurements in Sudan. The data is scattered in many places, and only dedicated researchers get hold of reasonable datasets on sediment.

Amongst the various players, the DIU is relatively new, as they started monitoring of hydrology and sediment at specific locations to serve new dams development. The use of new techniques has been initiated, as both MoIWR and DIU have ADCPs for discharge measurements. As also found by the Phase I Consultant, the DIU has made the best progress with the application of new advanced techniques. They have been assisted by for instance DHI Water &Environment (Denmark) in setting up a methodology for applying the ADCP at Merowe Dam. The 3 ADCPs belonging to DIU are in good working condition, while the three ADCPs belonging to MoIWR are damaged and never worked properly. A practical difficulty that both DIU and MoIWR are facing is the import embargo imposed on Sudan, which hits the import of advanced electronic equipment, including ADCP. A very positive development in Sudan is the extensive survey being done by French IGN mapping by LIDAR technique the shores of the Nile, and the corresponding hydrographic surveys of river cross sections. This activity, which is also guided by DIU, will make it possible to obtain a good vertical control and – hopefully – relate the various historical measurements that have been done to different reference levels. DIU is presently working on the design of a monitoring network for the Nile Basin in Sudan. Although this is an indication that DIU is taking an increasing responsibility for the entire monitoring network in Sudan, they have no ambition to take over the main responsibility of the monitoring system.

With so many institutions involved, the need for strong coordination is very high. It has not been possible to check sufficiently if this coordination really works. The immediate impression is that most likely it does not work very well. Coordination would be required In a number of fields, such as:

- overall monitoring strategy
- measured parameters
- measuring frequencies
- instrumentation approach
- experience sharing

- laboratory analysis approach
- data processing and quality assurance
- data formats
- data bases

The Nile Basin secretariat under the Water Resources Planning and Development Project is presently implementing the DSS for the entire Nile Basin. In its final form the DSS will *“serve as a shared knowledge base, provide analytical capacity, and support stakeholder interaction, for cooperative planning and management decision making for the Nile River Basin”*. The implementation is underway in Sudan, but at a slow pace, due to the present difficult situation in the Nile Basin cooperation. Once completed, the DSS will form a common basis, nationally in Sudan as well as within the Nile Basin countries.

Like in Ethiopia, there has been a decline in discharge measurements during latest decades. A comprehensive explanation of this problem has not been found. Measurement of sediment in Sudan is very intermittent, both temporarily and spatially. Suspended sediment load is calculated from measurements of silt concentration, while there are no measurements of bed load, but bed material samples are taken. Sediment measurements are done in all Q-stations but not as often as flow measurements.

A unique institution or department should be established to monitor the sediment flow in Sudan, and subsequently process, store, and disseminate the data. For smooth linking to hydrological data, the host is preferred to be within the MoIWR. The two potential departments could be the HRS in Wad Medani, or the Groundwater and Wadis Department at Khartoum. However, appropriate capacity building efforts in terms of staff training, field equipment, and lab instruments, is pre-requisite before any successful sediment monitoring program is thought of.

6.2.3 Egypt

The Phase I Consultant has made a comprehensive review of the monitoring in Egypt. The present report only considers the monitoring of Lake Nasser/Nubia. Extensive surveys and mathematical modelling is presently being carried out to monitor and understand the processes of sediment deposition in the Lake Nasser/Nubia. The surveys are carried out annually by the Aswan High Dam Authority (AHDA) and the Nile Research Institute (NRI). Participants from Sudan MoIWR take part in these annual monitoring programmes. The monitoring, which is extensive, involving measurements of numerous parameters, has been going on since the 70es.

It is recommended that this monitoring is continued with the involvement of the same institutions, but with a modernised setup and a critical review of required frequencies, as specified by SWECO (2007).

6.3 Monitoring Network

6.3.1 Ethiopia

The current overview and understanding of the monitoring is insufficient. Maps of the three catchments showing the existing stations, road network and catchment boundaries are under production by the Hydrology and Water Quality Directorate, assisted by the Geospatial and Geotechnic Directorate. The maps are still to be considered as working documents. The maps are incomplete on a number of points:

- Not all stations are included
- Some stations are wrongly marked
- Catchment boundaries need to be checked
- The numbers are not unique (same station numbers may be found in another catchment)
- The table relating the serial number of stations to Station Id. Is incomplete.
- The applied Station Id is too long for practical use as station name.
- The road map is not fully up to date.

Following the completion of the maps, various map combinations can be useful for improving the understanding of the purpose of each station. For example the station maps can be combined with:

- Rainfall map
- Soil erosion map
- Detailed catchment map

In addition it is useful to extend the road map to show even roads that are under construction and roads under design.

In the design of an optimized monitoring network, it is important to keep in mind the purpose of every station. Even in the operation of the network it is beneficial if everyone in the Hydrology and Water Quality Directorate has a good understanding of the use or potential use of the data that are being collected.

Along with further developing the monitoring at each station individually, different station characteristics may be shown.

This issue is coupled with the lack of someone assigned with the overall responsibility and overview of the entire monitoring network at the Hydrology and Water Quality Directorate.

Monitoring at most stations is insufficient. The reason is not entirely clear, but it appears that insufficient funding is allocated for monitoring. Lack of coordination and lack of staffing are other – possibly related – causes. Streamflow data cronograms were not available for the entire network, but a limited one covering 34 stations in Abbay Basin was produced by the NORPLAN JV, Figure 1.5. Out of the 34 stations only 11 had records available the last years up to 2010, and of these only 4 stations had complete annual records. Although this analysis covers a limited number of stations it clearly indicates that the Hydrology and Water Quality Directorate under MoEW is presently not able to provide anywhere near satisfactory data coverage in their monitoring network

Two possibilities to solve this issue should be considered. One is to cut down on the number of stations. This is realistic as many stations are placed quite high up in the river system, with relatively small station catchments. Unless there are very specific reasons to keep these stations, they may well be sacrificed, for the benefit of obtaining more measurements in the remaining stations. The other possibility is naturally to increase funding.

A combination of the two possibilities may be the optimal solution. Whichever solution is chosen, it is necessary to improve the organization of the monitoring work. Some initial work would include proper naming and mapping of monitoring stations, and showing them in various maps to illustrate not only their location but also their main purpose.

Road access has been the determining criterion in locating the existing stations. From a hydraulic/hydrological point of view this is of course not satisfactory, but in a steep terrain it is costly to establish and maintain off-road monitoring stations. As a result, monitoring is very sparse in less populated areas, and the locations of monitoring stations are, in general, far from optimal. Several stations are placed close to each other and high up in the catchment in smaller streams with relatively small run-off. Since budget is a constraint, such stations may be cancelled altogether – unless they are useful in connection with specific new developments. On the other hand, a number of river/road crossings have been identified, where it would be useful to establish monitoring stations. Future new roads may create more opportunities to establish stations with road access.

6.3.2 Sudan

The review of the network in Sudan has not been as detailed as in Ethiopia, so the comments are fewer. The numbers of stations are far less than in Ethiopia and the dependence on good road access is generally far less pronounced. But also here there is a general lack of understanding of the objectives of the monitoring. This naturally makes it difficult to understand the importance (or lack of importance) that set procedures and routines are adhered to. The intensity of measurements has reduced over the latest decades, without there being an obvious reason for this.

A thorough review should likely lead to a reduction of the number of stations required, although the reduction would be far less than proposed for Ethiopia. The review should take into account the stated objectives of the monitoring and decisions to discontinue monitoring at some secondary stations should only be taken after a thorough analysis and review of historical data collected from each station.

Monitoring at most stations is insufficient, but the reason is not entirely clear. If a review will result in discontinuation of a number of stations, this would improve the situation slightly, but likely not enough. Another possibility is to increase efficiency of especially discharge measurements. By application of modern measuring techniques, such as ADCP, discharge measurements could be done more efficiently and at a better quality. Another possibility is to increase funding, most likely both will be required.

6.3.3 Egypt

The present monitoring of Lake Nasser/Nubia, which is extensive, involving measurements of numerous parameters, has been going on since the 1970es and has established a ‘tradition’ for how the measurements should be done. The monitoring is very important for Egypt, and considerable resources are spent on it. The present Consultant reviewed this monitoring effort in detail during his involvement in the Watershed Management Fast Track Project for Egypt-Sudan (SWECO, 2007).

The impression at that time was that a lot of good data is being produced, but also that there is scope for improvement. As in Ethiopia and Sudan, there is a need to review the traditional methods and ask questions like:

- What are the result we want to achieve in the end?
- Why are we measuring exactly as we do, is it the most efficient way of getting to the goal?

With new technological advances, new opportunities arise, to obtain better data, maybe even at a lower cost.

SWECO (2007) reviewed the present setup recommended a comprehensive modernization of methodologies, and even recommended to look at the possibility of reducing the monitoring frequency for the large bathymetric survey, in order to spend the savings on other monitoring activities.

A weak point in the present monitoring is the lack of information on the porosity of sediment deposited in Lake Nasser/Nubia. SWECOs (2007) study recommended that this is determined as part of the monitoring.

It was further recommended that the modeling, which is already in use, should be strengthened even more and include modeling of the Nile upstream in Sudan (up to Merowe Dam). Hydraulic and sediment modeling would improve the quality of the monitoring effort at the same time as savings could be made on reduced measurements.

6.4 Measuring Techniques

6.4.1 Ethiopia

There are generally difficulties in the measurements of high flow velocities, at the stations managed by the MoWE as well as in the micro-watershed measurements of the Tana-Beles project. Apart from the practical difficulty, current meters get damaged when measuring close to the bed. Automatic water level recorders of different types have been established at numerous stations, but they are not functional. Reasons vary from unreadable German manuals to lack of paper rolls. Manual reading of staff gauges is a method that works well, but staff gauges are often damaged or missing. There is a risk of inaccuracy when a temporary gauge scale is painted on a bridge pier or abutment wall.

For future flow measurements with conventional current meters a methodology should be developed for measuring discharge, leaving out the measurement closest to the bottom at high flow conditions. This will cause some (minor) inaccuracy, but has to be weighed against the consequences of the damages to the current meter. Damages will still happen, some can be mended locally and some require spare parts from the manufacturer. Sufficient spare parts for instruments and associated equipment should be obtained and be stand-by during the flood season; some from instrument manufacturers, some produced locally.

In spite of the support from NVE for the monitoring at Kessie and Bure Bridges, the set-up even at these stations is inadequate and the instruments get damaged frequently. To improve the setup there is a need to design and procure locally a new and suitable crane/rig for use at Kessie Old Bridge and Bure Bridge (and maybe other places as well). Different locations will require different rig solutions, adapted to the bridge design.

The potential of the ADCP for discharge measurements and possibly even sediment concentrations has not been realized. Scott Wilson, NVE and MoWE have failed to realize the potential of the ADCP so far. The ADCP works well in Sudan under conditions of high sediment concentrations, in the setup used by DIU (not the ADCPs used by MoIWR), and should be adapted to work also in Ethiopia. It is recommended that the ADCP is tested and adapted to function, and then used for discharge measurements in key stations, later to be expanded into some non-key stations. Minimum two, probably three standard setup configurations will be required, dependent on site conditions. The possibility to even use the ADCP to measure sediment concentrations in the river should be tested.

Finally, the potential of using the Surface Velocity Radar (SVR) (see sec 5.6.2) in flow monitoring should be tested.

The more advanced water level measuring devices are usually not working, and even the staff gauges are often damaged. Several stations have some kind of automatic water level gauge, but the experience from the field trip is that it does not work. Pressure gauges still remains to be tested. Even the simple staff gauges are very often damaged, possibly from floating debris or vandalism.

The lessons from these experiences may be summarized as follows:

- Advanced new methods may be the way ahead for discharge measurements and for suspended sediment concentrations, where the instruments follow the mobile field crew
- Automatic methods for water level gauging has not been successful, but pressure gauges has not been tested
- Manual staff gauges for water levels are very sensitive to damage. In key stations consider more robust types like the ones used by the Egyptian Irrigation Department

6.4.2 Sudan

Although specific experiences in Sudan differ from those in Ethiopia, the lessons may be summarized in exactly the same way as stated above for Ethiopia.

With respect to the points mentioned, Sudan is, however, somewhat more advanced than Ethiopia. Advanced measuring techniques are working, just not implemented to the extent desirable (for instance the 3 ADCPs with DIU are working well). Sudan already has the ‘Egyptian type robust water level gauges.

Sand encroachment is less well understood, and monitoring is still at a research level without clear quantifications. The work, applying remote sensing techniques in combination with field measurements are promising, but quite demanding on resources before quantitative monitoring results can be achieved.

Sand encroachment and bank erosion are two important phenomena on the Main Nile. To properly understand and quantify their effect on the river morphology, mathematical modeling is required in combination with the monitoring.

6.4.3 Egypt

The monitoring of Lake Nasser/Nubia is technologically relatively advanced. The methods used have been continually updated, and the new Watershed Management Fast Track Project Egypt-Sudan, which is under implementation, is going to introduce State-of-the-Art monitoring methodologies. Thus, when it comes to Lake Nasser/Nubia, the monitoring situation is far better in Egypt than in the other two EN countries.

6.5 Laboratory Facilities

6.5.1 Ethiopia

The sediment laboratory facilities in Addis Ababa are small and very basic. The capacity is limited, partly due to faulty equipment. The reason it is not seen as a bottleneck in the present sediment monitoring system is probably that the collection of samples is very small. Once the need for sediment analyses is realized after a new monitoring system is designed, a laboratory with necessary capacity needs to be established. At present no bed samples are taken for grain size analysis. In the new setup the laboratory should have the necessary capacity and sets of sieves to do the grain size analysis.

In some cases it may be necessary to determine also the grain sizes of suspended sediment. This may be done by various methods, pipette method is one possibility. Whichever method is chosen, the laboratory needs to have the necessary laboratory equipment.

6.5.2 Sudan

Sudan has better laboratory capacity, but the number of samples taken is low. After a full review and a decision on the required number of samples, it is likely that more laboratory capacity will be required. Bed samples are already being taken, and sieves for grain size analysis are available at the HRS laboratory in Wad Madheni.

6.5.3 Egypt

NRI/AHDA have the required laboratory capacity. Even the laboratory capacity may need to be reviewed in connection with the upgrading of the Lake Nasser/Nubia Monitoring System.

6.6 Data Transfer

The following applies equally to Ethiopia and Sudan, although examples are taken from Ethiopia. Data transfer is an often slow manual process. In Ethiopia, measured data may be lying with the gauge reader for 3 months until they are picked up and transferred to Addis Ababa, where it will be processed and checked. In case of serious data problems it will again take a span of time till the error is rectified, and a whole flood season of data may be lost. The time required for data processing and proper quality check is unknown, but based on the information provided about capacity problems, this part may take several weeks or even months. There is a definite need to be able to transfer data to the Hydrology and Water Quality Directorate faster and in a more reliable way. There are presently ongoing efforts at Hydrology and Water Quality Directorate in Ethiopia to establish a telemetry system.

Real-time data transmission is a different issue. If the data should be used for flood forecasting/warning the transfer need to be fast – when data is transmitted automatically from an automatic water level gauge, the data are received real-time at the head quarter, and can be used immediately to issue warning against high water levels downstream. The data can also be entered in a flood forecasting model for more refined predictions of flood developments downstream. But unless there is a need for real-time data, there is no reason to establish such a system.

The data transfer in Egypt has not been looked into.

6.7 Data Analysis and Quality Assurance

6.7.1 Ethiopia

It is the impression that there is shortage of resources to do comprehensive QA based on analyses of data received. There is also a lack of firm guidelines on how to do the QA.

At present there is little feedback from data users, in spite of the fact that linkages with planned and ongoing projects are a main principle under the Water Sector Development Programme, 2002. Consultants and university scientists who obtain data from the Hydrology and Water Quality Directorate and analyze and apply the data in their research will often obtain a good understanding of the data, the quality of the information and ideas on how to improve the monitoring system and/or the analysis and quality checks. Sometimes this may appear from their hydrological study reports or from scientific papers. But this information is not communicated to the Hydrology and Water Quality Directorate, and even if it was, it would be doubtful if they would have sufficient resources to respond appropriately to such information. The Hydrology and Water Quality Directorate has sometimes received the databases developed by projects (for example Karadobi), but not had the resources to incorporate the information provided under their own database system.

Modelling would be a strong tool in the data quality assurance and the improvement of the monitoring system, but is not used.

6.7.2 Sudan

This aspect has not been investigated in sufficient detail to be able to give any firm statement on the status.

6.7.3 Egypt

This aspect has not been investigated in sufficient detail to be able to give any firm statement on the status, but the Consultant has good reason to believe that the status is considerably better as described for Ethiopia.

6.8 Resources and Staff Development

It is a general problem in both Ethiopia and Sudan to maintain the existing monitoring system. Lack of resources and lack of staff is given as explanations.

The underlying reason, however, is believed to be a lack of understanding at decision/political level of the importance and benefits of quality in monitoring. That understanding may be present at the technical level, but not communicated clearly to the decision makers. The misconception that hydrological data can be collected at short notice and at hardly any cost is unfortunately common in many countries.

It is a fact that the availability of reliable data is a considerable cost saving to projects, where structures can be optimized further, and the cost reduced. Once this is fully understood, the challenge is to transfer a fraction of these large cost savings to the establishment of a good monitoring system.

Maybe the most important in establishing a well-functioning monitoring system is well-qualified, well-trained and motivated staff. In order to attract them they need to be given the necessary resources to do their job.

At present, given the number of stations and the difficulties involved in maintaining a monitoring network in difficult natural conditions, there is lack of coordination of monitoring efforts and a lack of staffing.

The aspect of resources and staff development has not been considered for Egypt, but the Consultant has good reason to believe that the status is considerably better as described for Ethiopia.

7 Design of Monitoring System

The present chapter takes the first steps towards the design of improved monitoring systems. It has, however, not been possible to recommend a detailed new design. The design of a new monitoring system depends on numerous parameters, including findings from detailed analyses of the data obtained from each station, combined with the stated purposes of each monitoring station. Very comprehensive guidelines on the design of monitoring networks are given by the Hydrology Project (1999, 2001, 2003). Reference is made to a few of the manuals issued by this project, but many more are available from their web-site http://www.hydrology-project.gov.in/manuals_n.asp. It is recommended that these guidelines are used in EN countries. They are made for the Indian sub-continent, but are so general that they would apply to EN countries as well.

7.1 Principles of Design of Sediment Monitoring Network

A hydrological data network is a group of data collection activities that are designed and operated to address a single objective or a set of compatible objectives. A single network may consist of several types of stations or gauges if they are all contributing information to the network's objective.

In reality, however, the term network is frequently referring to an aggregation of gauges and stations that have no coherence in their objectives. This can cause confusion and false expectations when network analysis and design are being discussed among programme managers and hydrologists.

Ideally, a network design would be based on a maximization of the economic worth of the data that are collected. However, such is not either the case in the real world. In the majority of cases in water resources decision making, the economic impacts of hydrological data are hardly ever considered. Decisions are made based on the available data, and the option of delaying the decision to collect more data is often not explored.

The setup and application of mathematical modelling tools can create the coherence in a monitoring network that is often missing. Collected data feed into the models to create a tool for simulations of extreme or project scenarios. Predictions improve as the data basis is enhanced. The calibration/validation process and sensitivity analyses provide an understanding of the relative importance of the various measurements and stations.

The existing monitoring network appears to be set up realizing the fundamental need of data for:

- Discharge
- Water levels
- Sediment transport

Presumably, the network has been set up to fulfil the data need of a variety of development projects, without this need being realized in much detail. According to the MoWE, the feed-back from data users has been very sparse, with little opportunity to adapt the monitoring to the needs of the users.

Locations of monitoring stations have very clearly been chosen mainly based on one very practical criterion: Nearby road access. Unfortunately, in the Ethiopian highland in particular, this is a very valid criterion. It is unfortunate, because more interesting and more suitable measuring cross sections may be missed.

In order to be able to let other criteria than good road access guide the selection of measuring locations in the future, the following should be considered and investigated:

- willingness to invest more in monitoring (in access and optimal equipment)
- possibility to use lighter and more handy measuring equipment (such as ADCP for both flow and sediment, SVR for flow)

It may for instance be possible to reach new and more appropriate measuring locations through new (simple) roads or in some cases with a boat, in which case safe mooring facilities would be required.

Hopefully, this would in future lead to the selection of key monitoring stations that are not completely tied to the existing road network. New road developments open up for new potential monitoring sites. In the planning of new monitoring stations, plans for new roads have to be considered.

With the large development projects, hydropower plants in particular, the need for quality data is high, and the benefits of quality data in terms of optimized designs and associated cost savings for the developers, is very obvious. The opportunity to improve the monitoring system is therefore very good right now. Nevertheless, this opportunity has so far not lead to any substantial improvements.

No grain sizes (or fall velocities) are presently determined. This is surprising, as this would be very relevant information in connection with the new dam projects, to evaluate the sedimentation potential for the reservoirs. Grain sizes of bed material may be used to estimate the bed load in rivers where bed load is significant, and the grain size distribution for suspended sediment can be used to assess the portion of wash load in the suspended load transport.

7.1.1 Project needs

Projects involving storage and/or extraction of river water will need information on the sediment content in the water that is stored/extracted. This means the **concentration of sediment** as well as the **discharge** is required. Projects will need to determine the how much sediment will deposit and where. This depends on the **grain size distribution** of the sediment entering reservoirs/ponds/canals. Considering that discharge is required for other basic purposes, unrelated to sediments, adding information about:

- **Sediment concentration**, and
- **Grain size distribution** of transported sediment

may appear to be a relatively simple task.

Conditions vary with time, and it is necessary to have this information at any given time. The project hydrologists will be able to calculate for instance annual volume of sediment entering, deposition volumes etc. Naturally, continuous measurement is impossible in practice. Therefore, the final set of data required by a project will not be the raw data, but processed and elaborated data, where the measured data will be used to produce continuous time series, by interpolation/extrapolation procedures.

Project engineers, with responsibility for their project will, however, want to do a quality check of the data themselves and also assess the accuracy of the processed data. Therefore, receiving only the processed and elaborated data is not satisfactory. They will also need the background data such as:

- Measured water levels and measuring method
- Discharge rating curves with all the data points applied in the calculation
- Sediment rating curves with all the data points applied in the calculation
- Examples of raw flow measurement data and the calculation of discharge from these
- Examples of raw sediment concentration measurements and the calculation of sediment discharge from the raw data

All this background information should be accompanied by date, time and location.

7.1.2 Soil erosion and sediment transport

Soil erosion is in itself a threat to agriculture in many areas, as large volumes of fertile soils are lost. The eroded soils are washed into the rivers and transported downstream, where they are even causing problems, such as:

- Sedimentation in reservoirs reducing the useful life of the water storage reservoirs
- Sedimentation in irrigation canals
- Increased wear on turbines at hydropower stations

The long-term solution is to reduce soil erosion through improved watershed management, such as terracing of fields and other improvements to farming methods, reforestation, check dams in small and large streams with a risk of erosion etc. In order to do this efficiently, the erosion hot-spots need to be identified. This can be done in various ways, though:

a) soil loss modelling (USLE/RUSLE, SLEMSA and others)

b) detailed remote sensing analysis possibly combined with radioactive Caesium detection for quantification

c) identifying tributaries with particularly high sediment transport rates

Soil loss modelling has been applied for the Ethiopian highland (e. g. Setegn et al. 2008) and need no further explanation here. Detailed remote sensing analysis is believed to be able to give an important contribution to the identification of sheet and gully erosion areas, but falls outside the scope of the present report. Principles are explained in Annex 1. In identifying rivers with high sediment transport, the monitoring of sediment transport is the only way. In the initial setup of key stations, the available soil erosion maps can be used as guidance. But soil erosion is a complex process, which is even extremely sensitive to local variations in the determining parameters. Therefore, the reality may not be well reflected in the soil erosion maps. The actual sediment load carried by the rivers, on the other hand, is pure reality. The challenge is to measure it accurately, analyse the results and let the findings guide the next steps in development of an extended monitoring network. The extension of the network should be aimed at identifying as closely as possible the sources of the sediment transported in the rivers. With the sources identified, soil erosion prevention can be focused on the areas where the need is highest. The stations that were first established with the purpose of identifying erosion hot-spots can subsequently be used to monitor the effects in terms of reduced sediment transport in the rivers, as a result of the soil erosion prevention measures applied.

Downstream, there will be a need to assess not only the rate of sediment transport into the reservoirs, but also the grain size/fall velocity of the suspended sediment, in order to calculate the deposition. Pipette Withdrawal Tube method may be considered for this purpose.

7.1.3 Sediment transport data

The purpose of this section is to provide an understanding of what kind of information constitutes the sediment transport data needed in connection with any development project.

Basic sediment transport theory

Sediment may be transported as bed load or as suspended load. Bed load is the portion of the transport where sediment grains move with more or less continuous contact with the river bed, whereas suspended load has rare or no contact with the river bed. The suspended load is again categorized into suspended bed material and wash load. Wash load is the portion of the suspended load that is simply conveyed with the flow with no contact with the river bed and with no impact on fluvial morphological processes. It is commonly accepted to consider silt and clay fractions as wash load. The turbulence of the flowing water will (generally) keep these sediment fractions suspended in the water column all the way through the river system, from the sources to the sea or lake or man-made reservoirs where settlement will have time to take place. The wash load does not interact with the river bed and is therefore considered to have no impact on the river morphological development. What distinguishes wash load from the rest of the sediment transport by a river is that wash load is *supply limited*, whereas other categories of transport are *capacity limited*.

Supply limited means there has to be a source available, in the form of for instance an eroding bank of very fine material or the erosion of land slide masses, also comprising very fine material fractions. With no opportunity of deposition (in the form of lakes and reservoirs) the river will act like a conveyor belt and the wash load will not affect the river morphology. The transport of wash load at any given section will be proportional to the discharge. The wash load can be expected to be fairly uniformly distributed over the river cross section, except very close to a source. The concentration of wash load is not directly related to any flow parameter, but rather on events that have influenced the supply of fine sediment to the river.

Capacity limited means that the sediment carrying capacity of the river flow is a determining factor for the concentration of suspended bed material. The moving sediment may settle from time to time, thereby taking part in the formation of the river. The bed material load (concentration) depends on the flow velocities, which means the transport will depend on the discharge to some exponent >1.

Bed load constitutes a relatively insignificant portion of the total sediment transport in most of the Nile River tributaries in EN countries, although it may constitute a significant contribution locally, in some rivers in the upper part of the catchment in Ethiopia, in the Tekeze and some Abbay tributaries. Bed load, by the deposition/erosion processes along the river, contributes to the river morphological process i. e. the formation of the river channel. The bed load is fully capacity limited, which means that in principle it can be determined from measured or simulated flow conditions. This is fortunate, since it is extremely difficult to measure the bed load with adequate accuracy. Therefore, in general, it is considered unnecessary to measure the bed load. In the rivers where bed load is assessed to be an important contribution to the sediment load, or if required for specific purposes, the approximate magnitude of the bed load can be calculated. The calculation is based on a few samples of the sediment in the river bed at each time of calculation, along with the discharge measurements carried out at the same time. The calculation requires the grain size distribution of the top layer of the bed sediment, which needs to be determined by sieve analysis in the laboratory.

7.1.4 Sedimentation in reservoirs

The sedimentation in reservoirs is a big problem to dam owners as it reduces the useful capacity and life of the reservoir. With numerous dam projects in the Nile Basin, the dams even affect each other (from upstream to downstream). For instance, the improved sediment management of the Sudanese dams caused increased sedimentation in the Lake Nasser/Nubia. But the reservoirs are also a very important source of information about the sediment transport entering the Reservoir. Over approximately 10 year periods from mid 60es to mid 70es the storage losses due to sedimentation at Roseires and Khasm el Girba were both above 0.5 km^3 (Garzanti et al, 2006). Bashar et al (2010) provides a good overview of reservoir sedimentation in Sudan and Egypt including the development of sedimentation with time in the various reservoirs. Modernization of methodologies to determine reservoir sedimentation are suggested by SWECO(2007).

Bathymetric surveys of reservoirs provide useful information to the dam owner; at the same time it is a useful source of information about the general sediment transport conditions in the rivers.

In principle, the bathymetric survey of a reservoir is relatively simple, considering todays advanced positioning technology (see Annex 2). A source of uncertainty is the density of the deposited sediment. This will have to be assessed through bed sampling.

Annex 2 first describes a methodology that will apply to most reservoirs. Finally, in section 9, the more advanced method described by SWECO (2007) for Lake Nasser/Nubia is summarized. This Monitoring System is presently under implementation. It is recommended that the lessons drawn from this project are used to form a general methodology for reservoir monitoring in EN countries, probably with more than one monitoring setup, depending on reservoir size and other characteristics.

7.1.5 Modelling

Models (hydrological, hydrodynamic, sediment) are powerful tools, not only in the assessment of future development options, but even to ‘fill the gaps’ between monitored data and checking the quality of the data. It is recommended that appropriate models are set up, to begin with in selected sub-basins. If this is done in parallel with the design of the monitoring network, both the modelling and the monitoring stand to gain. The modelling need quality data, for the model to be of value, and the monitoring network can be optimised with the benefit of a model, so that stations may later be omitted.

Limited modelling has been done and with somewhat mixed outcome. It is a common opinion often found in the literature that the reason is that modelling tools are developed for conditions in Europe or North America, that are very different from the natural conditions in Ethiopia, e. g. Seleshi et al (2009). It is true that conditions are different, but it is believed that the main reason behind modelling problems is the lack of good data.

The runoff in a catchment is usually the relatively small difference between two much larger quantities: the rainfall and the evaporation.

As an example (SMEC 2008), the average annual water balance terms of the Abbay Basin is as follows:

Rainfall: 1197 mm/year

Runoff: 243 mm/year

Evapotranspiration: 954 mm/year

Rainfall is measured, though the density of rainfall stations should be increased, but there is a more severe lack of measurements of evapotranspiration.

7.1.6 Summary

Taking all of these aspects into consideration, the guiding principles in the design of key monitoring network for sediment transport should be:

1. The sediment transport in the NILE in EN countries will predominantly take place as suspended load, but in some rivers in the upper catchment in Ethiopia bed load may be considerable. Suspended load should be measured while bed load, which is difficult to measure, may be calculated based on flow velocities and measured bed material grain sizes, in rivers with a significant contribution from bed load.
2. The transport and deposition characteristics of fine sediments (silt and clay), can be characterized as wash load. Due to the special physical characteristics of this portion of the sediment transport it is of interest to determine the fraction of fines in the suspended load; preferably even the full grain size distribution of suspended sediments.
3. In project applications of the data it is not sufficient that the institution responsible for the monitoring supplies the processed and elaborated data in terms of time series of sediment transport. Preferably, these need to be accompanied by background information in the form of:

- Measured water levels and method
- Discharge rating curves with all the data points applied in their calculation
- Sediment rating curves with all the data points applied in their calculation

- Examples of raw flow measurement data and the calculation of discharge from these
- Examples of raw sediment concentration measurements and the calculation of sediment discharge from these

4. Modelling can create the coherence in a monitoring network that is often missing. Measured data feed into the models to create a tool for simulations of extreme or project scenarios. Predictions improve as the data basis is enhanced. The calibration/validation process and sensitivity analyses provide an understanding of the relative importance of the various measurements and stations, and the model becomes a tool in the data quality checking.

The purpose of sediment monitoring should be clear and guide the design and continued maintenance of the monitoring network. Better management of the sediment that is eroding and transported within the river basin is an overarching purpose. Sediment monitoring can assist in:

- Providing sediment information for identifying/mapping soil erosion areas
- Provide sediment information for sedimentation sensitive structures (reservoirs, canals etc)

Thus, some guiding principles for the design of the sediment monitoring network are:

1. Stations should be placed where they would be able to capture the sediment transport originating from areas with heavy soil erosion
2. Stations should be placed upstream of reservoirs and other developments that would benefit from the information about the sediment inflow. Not only the amount, but also the grain size distribution should be determined by the monitoring.
3. The development of the monitoring network should be in stages. The results of a first development should be analysed and guide the setup of additional stations in the attempt to identify areas of high soil erosion
4. After high erosion areas are identified and erosion reduction measures implemented, the established monitoring network changes its purpose: Now it will detect the effect of the implemented erosion reduction measures on the sediment transport in the rivers
5. At some time in the future, when soil erosion has been reduced through various mitigation measures, and the sediment transport in river branches has stabilized at a low level, some stations may be taken out of operation
6. The design of a monitoring network should preferably be done in parallel with the establishment of a hydrodynamic and sediment modelling system for the river system

It has to be remembered that in areas of heavy soil erosion, large amounts of sediment is often accumulated in the river channel. This in-channel sediment will contribute to the sediment transport for quite some time after the supply of new sediments have reduced due to for instance various soil conservation measures. It is therefore to be expected that such measures take some time before they can be registered as reduced sediment transport in the rivers.

7.2 Organization of Monitoring

7.2.1 General

The responsibility for monitoring is generally isolated from the application of the data that are collected. Moreover, with little or no feedback from data users, the organization in charge of the monitoring easily lose touch with the application and purpose of the monitoring they are doing. It is believed, that in the near future, mathematical models will be set up various parts of the Nile Basin and with a variety of purposes. These models should be handed over to a national institution responsible for the maintenance and continued application of at least some of these models. By placing the responsibility of flow and sediment monitoring close to the section that in the near future will be responsible for hydrologic/hydrodynamic and sediment modeling, this will make the usefulness of the monitoring more visible, which will make the purpose of monitoring more clear and enhance the motivation of the staff involved,

Centralised planning, quality check and analyses seems the most appropriate, while delegation of as many field tasks as practically possible is expected to increase efficiency of the monitoring operation.

The coordination of all monitoring should be ensured by appointing one coordinator who is responsible for coordinating all monitoring efforts, including staffing and training, setup and repairs at monitoring stations, overviews of available data and data quality checking. The coordinator should receive feedback from the data users and adapt monitoring/processing/publication accordingly.

Once a clear and well justified plan for the monitoring network is ready, it is recommended that the necessary funding is sought or allocated for monitoring. Data is a highly valuable basis for all water resources development projects. The availability of quality data may lead to very considerable cost savings, exceeding many times the cost of maintaining the monitoring system. How to cover the cost of the monitoring system remains a question for politicians to answer.

7.2.2 Ethiopia

Centralised planning, quality check and analyses is the most appropriate under the current conditions, while delegation of as many field tasks as practically possible to the branch offices is expected to increase efficiency of the monitoring operation. Once River

Basin Authorities (RBA) have been established it may be considered if some of the centralized functions should be moved to the RBAs.

In Ethiopia, rainfall and evaporation data collected by NMA are important input to hydraulic models. The host of hydraulic models should preferably have very close connection to the two monitoring organizations. It would therefore be appropriate to join the responsibilities of hydrologic and meteorological monitoring as well as hydraulic modeling within one closely linked organization. One possibility would therefore be to place the Hydrology & Water Quality Directorate under the National Meteorological Agency together with a national surface water modeling unit, responsible of hosting and maintaining hydraulic models handed over from various projects. There would be several other organizational options that would fulfill the main objective of creating a stimulating working environment that include:

- Hydrological/sediment/water quality monitoring
- Rainfall/evaporation monitoring
- Rainfall runoff/hydraulic and sediment modelling

The coordination of all monitoring should be ensured by appointing one coordinator who is placed centrally, responsible for coordinating all monitoring efforts, including staffing and training, setup and repairs at monitoring stations, overviews of available data and data quality checking. The coordinator should receive feedback from the data users and adapt monitoring/processing/publication accordingly.

Once a clear and well justified plan for the monitoring network is ready, it is recommended that the necessary funding is sought or allocated for monitoring. Data is a highly valuable basis for all development projects.

7.2.3 Sudan

Contrary to Ethiopia, local rainfall in Sudan usually comprises an insignificant portion of the total runoff. Meteorology plays a less prominent role although rainfall and evaporation data will quite often be sought for modeling exercises. It is recommended that in Sudan, the hosting of hydraulic models should be under the same organization that is responsible for the hydrologic monitoring. Since MoIWR (NWD) has historically had the main responsibility for the monitoring system in Sudan, it is suggested that it is kept this way. Hosting and maintenance of hydraulic models is recommended to be the responsibility of a new section under the MoIWR.

Centralised planning, quality check and analyses seems the most appropriate, while delegation of as many field tasks as practically possible is expected to increase efficiency of the monitoring operation. Since there is an established tradition of making use of the services of HRS and DIU. The essential change is that it should be very clear that MoIWR is in charge of monitoring and has overall responsibility for the system and its function.

The coordination of all monitoring should be ensured by appointing one coordinator within the MoIWR, who is responsible for coordinating all monitoring efforts, including staffing and training, setup and repairs at monitoring stations, overviews of available data and data quality checking. The coordinator should receive feedback from the data users and adapt monitoring/processing/publication accordingly.

Once a clear and well justified plan for the monitoring network is ready, it is recommended that the necessary funding is sought or allocated for monitoring. Data is a highly valuable basis for all water resources development projects. The availability of quality data may lead to very considerable cost savings, exceeding many times the cost of maintaining the monitoring system. How to cover the cost of the monitoring system remains a question for politicians to answer.

7.3 Monitoring Network

The main objective of the present study is to strengthen sediment monitoring. Sediment monitoring is closely related to hydrological monitoring and in this report no clear distinction is made, except the following:

- For any station where sediment monitoring has been done, the sediment data obtained should be evaluated in order to decide if sediment monitoring should be continued or not
- If the sediment data collected at that station does not provide a clear picture of the sediment transport conditions at the site, measurements may be continued, maybe even intensified in order to obtain a clear picture.
- Suggested new stations are combined hydrological and sediment monitoring stations.

As described earlier, the differences between Sudan and Ethiopia are pronounced. This applies to sediment processes as well as to the density of the monitoring. After a brief review of the network in Sudan, the present Consultant agrees with the Phase I Consultant on most points. The need to revise the monitoring network is clearly less pronounced in Sudan than in Ethiopia, although the use of mathematical modeling would lead to more efficient monitoring with substantial savings. At present there has been no reason to suggest changes to the Sudanese monitoring network. With the new border to South Sudan, a new border station on the White Nile needs to be established.

From this point, the analysis of the monitoring network will deal mainly with the Nile catchments in Ethiopia.

The WMO Manual on Stream Gauging, section 2.2, describes various categories of stations, depending on particular conditions in the basin. It is strongly recommended that these guiding principles are reviewed prior to the final design of the monitoring network. The present review and recommendations does not take into account all such considerations since it has not been possible to obtain all the information required about for instance on-going developments.

The WMO Stream Gauging Manual operates with two basic types of gauging station, namely hydrologic and special stations. The special stations are project related (future or existing), whereas hydrologic stations are not project related in their origin, although they may become useful in connection with projects. Both hydrologic and special stations may be operated permanently or temporarily. Permanently operated hydrologic stations are named principal or primary hydrologic stations. A temporarily operated station is operated long enough to establish the flow characteristics of their watershed and in some cases their correlation with a principal hydrologic station. It is assumed that similar principles will apply to sediment gauging stations.

The existing monitoring network in both Ethiopia and Sudan consist of permanent stations, although some are not monitored year-round.

It is believed that the principles of temporary stations should be applied for hydrological as well as sediment monitoring. After a critical review of each individual station it can be decided if a station should be kept as a permanent monitoring station, be downgraded to temporary monitoring or be discontinued. The purpose would be to make the monitoring effort more efficient.

The density of monitoring stations is highly variable, in particular in Ethiopia. Here stations high up in the river catchment with only small station catchments may be discontinued or downgraded.

The station networks in Abbay,Tekeze and Baro Akobo basins have been reviewed based on mapped basin characteristics (see Annex 3) with the aim to determine a more appropriate monitoring network. The following criteria have been applied, somewhat subjectively:

- Monitoring stations that have relatively small station catchments may be discontinued (unless they serve a specific purpose i. e. they are special stations).
- New stations should be established at road/river crossings when these have larger station catchments. Where new roads or road improvements are planned, new options of placing a station may arise.
- Sediment monitoring stations should be established in areas with high soil erosion in the attempt to – with time – identify the sources. Such stations may be temporary.

Constraints in the selection have been the inaccuracies in the data provided by the Hydrology and Water Quality Directorate. Some stations are not shown and some are indicated far from the river (either the river is shown wrongly or the station is). Due to these constraints, the following results should be seen as temporary.

Generally, the suitability of station locations should be reviewed. It was found during the field trips that in several cases the station location was not the most optimal in the area. In those cases the stations should be shifted. When a station is shifted, however, it should be given a number or identifier that clearly distinguishes it from the old location, so that data from the two locations are not unintentionally mixed in the analysis.

The following analysis, catchment by catchment, aims at revising the present monitoring network for hydrology and sediment. In all cases, the proposed number of stations is reduced. Several stations are proposed to be discontinued, fewer new stations are added. A basis for the proposed changes are the maps shown in Annex 3. This is by no means a final proposed layout. A close review and assessment of the purpose of a station should be done before it is decided to cancel it. Likewise, no new stations should be set up until their usefulness has been discussed in detail and the locations have been visited.

Abbay Basin

The present number of stations is approximately 124 (of these 20 without assigned station ID). Of these stations, approximately 36 of them should be kept as year round measuring stations, whereas 90 stations should be either discontinued or evaluated for downgrading. In the evaluation, the usefulness of each station should be assessed, considering:

- station catchment
- flow character and special problems in the area such as flooding or erosion
- ongoing developments in the area
- historical hydrologic and sediment data

Following the station assessment, stations may be discontinued or downgraded to temporary or seasonal monitoring. Before a station is removed, it is important that the historical data from that station is analysed thoroughly in the attempt to establish rating curves. Both the rating curves and the analysed data used shall be kept along with all raw data.

The exact locations of the stations to be kept need to be reviewed to make sure the cross section is acceptable for monitoring; otherwise, the station should be shifted to nearest suitable location.

It is presumed that the temporary station at Bure Bridge on the Abbay is continued as a permanent station.

A total of 10 potential new station locations have been identified (11 are marked in Figure 8 but with two being alternatives). All 10 appear to have good road access. These 10 road crossing locations were selected where the potential station catchment is considerable.

From a hydrological point of view there should be more monitoring stations in some of the areas with poor road access. Some of the most interesting reaches to monitor would be:

- Abbay along the reach from the Bechelo confluence and Kessie Bridge.
- Bechelo River between Bechelo Bridge and Abbay confluence.
- Guder at Abbay confluence.

A number of other larger tributaries should be monitored close to their confluence with Abbay.

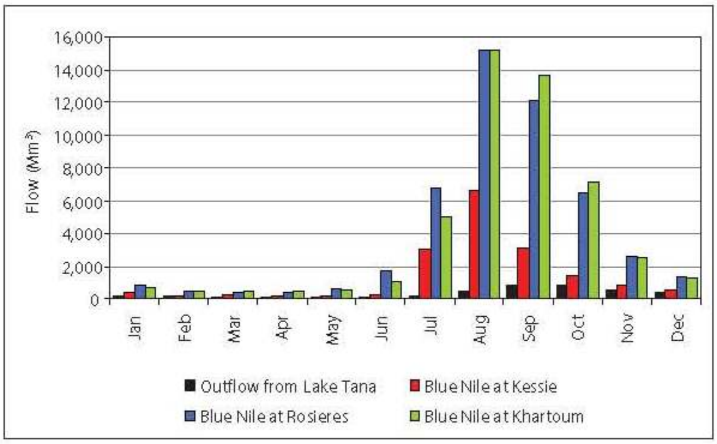


Figure 7 Monthly flow at main Abbay/Blue Nile stations showing the large inflow between Kessie and Roseries. (from Seleshi et al, 2008)

Figure 7 above illustrates the need for more stations on the main Abbay between Kessie and Border as the flow approximately doubles along this reach. At present there is only one station along this reach, the station at Bure Bridge.

The total number of stations in the Abbay Basin after this review ends at 47 stations, a reduction to less than half of the present number.

At the same time as the number of stations is reduced, the frequency of discharge and sediment measurements should be increased substantially. At the same time, there should be a continuous review of the measurements on the basis of which it is decided if a station should remain or not.

Table 2a Monitoring stations in Abbay Basin. Stations in red Itallics are the stations proposed to be continued.

NO	CATCHM	SUBCATCHM	STN ID	RIVER/LAKE	SITE	KM2	STATION NAME
1	*ABBAY*	*LAKE TANA*	*111001*	*LAKE TANA*	*@ BAHIR D*	*15 319*	*LAKE TANA@ BAHIR D*
2	*ABBAY*	*LAKE TANA*	*111002*	*GELGEL A.*	*Nr. MARAW*	*1 664*	*GELGEL A.Nr. MARAW*
3	ABBAY	LAKE TANA	111003	KOGA	@ MERAWI	244	KOGA@ MERAWI
4	*ABBAY*	*LAKE TANA*	*111004*	*LAKE TANA*	*@ GORGORA*	*15 319*	*LAKE TANA@ GORGORA*
5	*ABBAY*	*LAKE TANA*	*111005*	*RIBB*	*Nr. ADDIS*	*1 592*	*RIBBNr. ADDIS*
6	*ABBAY*	*LAKE TANA*	*111006*	*GUMARA*	*Nr. BAHIR*	*1 394*	*GUMARANr. BAHIR*
7	*ABBAY*	*LAKE TANA*	*111007*	*MEGECH*	*Nr. AZEZO*	*462*	*MEGECHNr. AZEZO*
8	*ABBAY*	*LAKE TANA*	*111009*	*UPPER RIB*	*ON D.TABO*	*844*	*UPPER RIBON D.TABO*
9	ABBAY	LAKE TANA	111010	ANGAREB	Nr. GONDE	41	ANGAREBNr. GONDE
10	ABBAY	LAKE TANA	111011	LAKE TANA	@ KUNZILA	15 319	LAKE TANA@ KUNZILA
11	ABBAY	LAKE TANA	111013	ZUFIL	Nr. DEBRE		ZUFILNr. DEBRE
12	ABBAY	LAKE TANA	111014	GELDA	Nr. AMBES	32	GELDANr. AMBES
13	ABBAY	LAKE TANA	111015	RIBB	Nr. GASAI	59	RIBBNr. GASAI
14	ABBAY	LAKE TANA	111016	GEMERO	Nr. MAKSE	174	GEMERONr. MAKSE
15	ABBAY	LAKE TANA	111017	FEGODA	Nr ARB GE	29	FEGODANr ARB GE
16	ABBAY	LAKE TANA	111018	GARNO	Nr. INFRA	94	GARNONr. INFRA
17	ABBAY	LAKE TANA	111019	EZANA	Nr. BAHIR	78	EZANANr. BAHIR
18	ABBAY	LAKE TANA	111020	BERED	@ MEREWI	81	BERED@ MEREWI
19	ABBAY	LAKE TANA	111021	AMEN	@ DANGILA	89	AMEN@ DANGILA
20	*ABBAY*	*UPPERNILE*	*112001*	*ABBAY*	*Nr. KESSI*	*65 784*	*ABBAYNr. KESSI*
21	ABBAY	UPPERNILE	112002	MUGHER	Nr. CHANC	489	MUGHERNr. CHANC
22	ABBAY	UPPERNILE	112003	ABBAY	@ BAHIR D	15 321	ABBAY@ BAHIR D
23	ABBAY	UPPERNILE	112004	ANDASSA	Nr. BAHIR	573	ANDASSANr. BAHIR
24	ABBAY	UPPERNILE	112007	BERESSA	Nr. DEBRE	211	BERESSANr. DEBRE
25	ABBAY	UPPERNILE	112009	WIZER	Nr. MEHAL	23	WIZERNr. MEHAL
26	ABBAY	UPPERNILE	112010	CHACHA	@ CHACHA	42	CHACHA@ CHACHA
27	ABBAY	UPPERNILE	112011	SHY	Nr. MEHAL	68	SHYNr. MEHAL
28	ABBAY	UPPERNILE	112012	ALELTU	Nr. CHANC	29	ALELTUNr. CHANC
29	ABBAY	UPPERNILE	112013	DENEBA	Nr. CHANC	86	DENEBANr. CHANC
30	ABBAY	UPPERNILE	112014	SIBILU	Nr. CHANC	375	SIBILUNr. CHANC
31	ABBAY	UPPERNILE	112015	ROBA	NR. CHANC	15	ROBANR. CHANC
32	ABBAY	UPPERNILE	112016	SHINA	Nr. ADIET	111	SHINANr. ADIET
33	*ABBAY*	*UPPERNILE*	*112017*	*MUGA*	*Nr. DEJEN*	*375*	*MUGANr. DEJEN*
34	ABBAY	UPPERNILE	112018	AZUARI	Nr. MOTA	209	AZUARINr. MOTA
35	ABBAY	UPPERNILE	112019	TIGDAR	Nr.GUNDE		TIGDARNr.GUNDE
36	ABBAY	UPPERNILE	112020	GEBREGURA	Nr. DEGOL	162	GEBREGURANr. DEGOL
37	ABBAY	UPPERNILE	112021	SELGI	Nr. KABE	93	SELGINr. KABE
38	ABBAY	UPPERNILE	112022	MECHELA	Nr. KABE	177	MECHELANr. KABE
39	ABBAY	UPPERNILE	112023	JOGOLA	@ WEREILU	31	JOGOLA@ WEREILU
40	*ABBAY*	*UPPERNILE*	*112027*	*ALELTU*	*Nr. MUKA*	*447*	*ALELTUNr. MUKA*
41	*ABBAY*	*UPPERNILE*	*112028*	*ROBI JIDA*	*Nr. MUKA*	*762*	*ROBI JIDANr. MUKA*
42	*ABBAY*	*UPPERNILE*	*112029*	*ROBIGUMER*	*Nr. LEMI*	*887*	*ROBIGUMERNr. LEMI*

Table 2b Monitoring stations in Abbay Basin. Stations in red Itallics are the stations proposed to be continued.

NO	CATCHM	SUBCATCHM	STN ID	RIVER/LAKE	SITE	KM2	STATION NAME
43	ABBAY	UPPERNILE	112030	TEME	Nr. MOTA	156	TEMENr. MOTA
44	ABBAY	UPPERNILE	112031	SUHA	Nr. BICHE	359	SUHANr. BICHE
45	ABBAY	UPPERNILE	112032	BOREDA	Nr. MEKAN	45	BOREDANr. MEKAN
46	ABBAY	UPPERNILE	112033	LEGE CORA	Nr. MEKAN	51	LEGE CORANr. MEKAN
47	*ABBAY*	*UPPERNILE*	*112034*	*JEMMA*	*Nr. LEMI*	*5 412*	*JEMMANr. LEMI*
48	ABBAY	UPPERNILE	112036	MENDEL	Nr. TIS A	72	MENDELNr. TIS A
49	*ABBAY*	*UPPERNILE*	*112037*	*SEDIE*	*Nr. MOTA*	*209*	*SEDIENr. MOTA*
50	ABBAY	UPPERNILE	112038	YEDA	Nr. AMBER	125	YEDANr. AMBER
51	ABBAY	UPPERNILE	112039	CHENA	Nr. ISTAY	33	CHENANr. ISTAY
52	ABBAY	UPPERNILE	112040	WENKA	Nr. ISTAY	110	WENKANr. ISTAY
53	ABBAY	MIDDEL N.	113001	BELLO	Nr. GUDER	290	BELLONr. GUDER
54	ABBAY	MIDDEL N.	113002	FATTO	Nr. GUDER	96	FATTONr. GUDER
55	ABBAY	MIDDEL N.	113005	GUDER	@ GUDER	524	GUDER@ GUDER
56	*ABBAY*	*MIDDEL N.*	*113008*	*CHEMOGA*	*Nr. DEBRE*	*364*	*CHEMOGANr. DEBRE*
57	*ABBAY*	*MIDDEL N.*	*113011*	*JEDEB*	*Nr. AMA N*	*305*	*JEDEBNr. AMA N*
58	ABBAY	MIDDEL N.	113012	GUDLA	@ DEMBECH	242	GUDLA@ DEMBECH
59	*ABBAY*	*MIDDEL N.*	*113013*	*BIRR*	*Nr. JIGA*	*978*	*BIRRNr. JIGA*
60	*ABBAY*	*MIDDEL N.*	*113014*	*TEMCHA*	*Nr. DEMBE*	*406*	*TEMCHANr. DEMBE*
61	ABBAY	MIDDEL N.	113015	LEZA	Nr. JIGA	175	LEZANr. JIGA
62	ABBAY	MIDDEL N.	113017	LAH	Nr. FINOT	288	LAHNr. FINOT
63	ABBAY	MIDDEL N.	113019	FETTAM	@ TILILE	282	FETTAM@ TILILE
64	*ABBAY*	*MIDDEL N.*	*113023*	*DURA*	*Nr. METEK*	*539*	*DURANr. METEK*
65	*ABBAY*	*MIDDEL N.*	*113026*	*NESHI*	*Nr. SHAMB*	*322*	*NESHINr. SHAMB*
66	ABBAY	MIDDEL N.	113028	DONDOR	Nr. METEK	184	DONDORNr. METEK
67	ABBAY	MIDDEL N.	113029	ARDY	Nr. METEK	219	ARDYNr. METEK
68	ABBAY	MIDDEL N.	113031	HULUKA	Nr. AMBO	184	HULUKANr. AMBO
69	ABBAY	MIDDEL N.	113033	QUASHINI	Nr. ADDIS	42	QUASHININr. ADDIS
70	ABBAY	MIDDEL N.	113034	BUCHIKSI	Nr. KIDAM	106	BUCHIKSINr. KIDAM
71	*ABBAY*	*MIDDEL N.*	*113036*	*L. FETTAM*	*@ GALIBED*	*757*	*L. FETTAM@ GALIBED*
72	*ABBAY*	*MIDDLE N.*	*113037*	*DEBIS*	*Nr.GUDER*	*799*	*DEBISNr.GUDER*
73	ABBAY	MIDDEL N.	113038	INDRIS	@ GUDER	111	INDRIS@ GUDER
74	ABBAY	MIDDLE N.	113039	BOGENA	@ LUMAME	166	BOGENA@ LUMAME
75	ABBAY	MIDDLE N.	113040	MISSINI	@ KOSSOBE	16	MISSINI@ KOSSOBE
76	ABBAY	MIDDLE N.	113041	ABAHIM	@ DEBREMA	31	ABAHIM@ DEBREMA
77	*ABBAY*	*DIDESSA-A*	*114001*	*DIDESSA*	*Nr. ARJO*	*9 981*	*DIDESSANr. ARJO*
78	*ABBAY*	*DIDESSA-A*	*114002*	*ANGAR*	*Nr. NEKEM*	*4 674*	*ANGARNr. NEKEM*
79	*ABBAY*	*DIDESSA-A*	*114003*	*SIFA*	*Nr. NEKEM*	*951*	*SIFANr. NEKEM*
80	ABBAY	DIDESSA-A	114004	WAMA	Nr. NEKEM	844	WAMANr. NEKEM
81	*ABBAY*	*DIDESSA-A*	*114005*	*DABANA*	*Nr. ABASI*	*2 881*	*DABANANr. ABASI*
82	ABBAY	DIDESSA-A	114006	UKE	Nr. NEKEM	202	UKENr. NEKEM
83	*ABBAY*	*DIDESSA-A*	*114007*	*LITTLE AN*	*@ ANGAR G*	*3 742*	*LITTLE AN@ ANGAR G*

Table 2c Monitoring stations in Abbay Basin. Stations in red Itallics are the stations proposed to be continued.

NO	CATCHM	SUBCATCHM	STN ID	RIVER/LAKE	SITE	KM2	STATION NAME
84	ABBAY	DIDESSA-A	114008	YEBU	@ YEBU	47	YEBU@ YEBU
85	ABBAY	DIDESSA-A	114009	URGESSA	Nr. GEMBE	19	URGESSANr. GEMBE
86	ABBAY	DIDESSA-A	114010	TATO	Nr. GUTIE	43	TATONr. GUTIE
87	ABBAY	DIDESSA-A	114012	INDRIS	Nr. SIRE	49	INDRISNr. SIRE
88	ABBAY	DIDESSA-A	114013	DABANA	Nr. BUNOB	47	DABANANr. BUNOB
89	*ABBAY*	*DIDESSA-A*	*114014*	*DIDESSA*	*Nr. DEMBI*	*1 806*	*DIDESSANr. DEMBI*
90	ABBAY	DIDESSA-A	114019	TEMSA	Nr. AGARO	48	TEMSANr. AGARO
91	*ABBAY*	*DABUS (5)*	*115002*	*DABUS*	*Nr. ASOSA*	*10 139*	*DABUSNr. ASOSA*
92	ABBAY	DABUS (5)	115003	HOHA	Nr. ASOSS	161	HOHANr. ASOSS
93	ABBAY	DABUS (5)	115004	HUJUR	Nr. NEDJO	94	HUJURNr. NEDJO
94	ABBAY	DABUS (5)	115005	HAFFA	Nr. ASSOS	194	HAFFANr. ASSOS
95	ABBAY	DABUS (5)	115006	SECHI	Nr.MENDI	562	SECHINr.MENDI
96	ABBAY	DABUS (5)	115007	GAMBELLA	Nr. ASOSS	6	GAMBELLANr. ASOSS
97	ABBAY	DABUS (5)	115008	ALELTU	@ NEDJO	168	ALELTU@ NEDJO
98	ABBAY	DABUS (5)	115009	DILLA	Nr. NEDJO	69	DILLANr. NEDJO
99	ABBAY	DABUS (5)	115010	KOMIS	Nr. GORI	112	KOMISNr. GORI
100	ABBAY	DABUS (5)	115011	MUTSA	Nr. BAMBA	16	MUTSANr. BAMBA
101	*ABBAY*	*LOWER AB.*	*116002*	*ABBAY*	*@ SUDAN B*	*172 254*	*ABBAY@ SUDAN B*
102	*ABBAY*	*LOWER AB.*	*116004*	*GILGEL BE*	*Nr. MANDU*	*675*	*GILGEL BENr. MANDU*
103	*ABBAY*	*LOWER AB.*	*116005*	*MAIN BELE*	*@ BRIDGE*	*3 431*	*MAIN BELE@ BRIDGE*
104	ABBAY			ADIYA	Nr. NEKEM	9	ADIYANr. NEKEM
105	ABBAY			ABBAY	Nr. BURE	110	ABBAYNr. BURE
106	ABBAY			ABBAY	Nr. PEDAG	14 369	ABBAYNr. PEDAG
107	ABBAY			AYO	Nr. KOSSO	41	AYONr. KOSSO
108	ABBAY			BUSO	Nr. BOREN		BUSONr. BOREN
109	ABBAY			CHEREKA	@ YECHERE	49	CHEREKA@ YECHERE
110	*ABBAY*			*TILKU DUB*	*Nr. DUBER*	*225*	*TILKU DUBNr. DUBER*
111	ABBAY			GERADO	Nr. DESSI	106	GERADONr. DESSI
112	ABBAY			GERBI	Nr. SULUL	89	GERBINr. SULUL
113	*ABBAY*		*112044*	*GORFO*	*Nr. GORFO*	*49*	*GORFONr. GORFO*
114	ABBAY			KELKEL	Nr. GOBIE		KELKELNr. GOBIE
115	ABBAY			KILTI	Nr. DURBE		KILTINr. DURBE
116	ABBAY			KORICHE	Nr. KILTU	64	KORICHENr. KILTU
117	ABBAY			MELKE	Nr. GUDER	139	MELKENr. GUDER
118	ABBAY			SHELKOLE	Nr. KOMOS	159	SHELKOLENr. KOMOS
119	ABBAY			TALIA	Nr. JIGA	607	TALIANr. JIGA
120	ABBAY			TINSHU DU	Nr. DUBER	104	TINSHU DUNr. DUBER
121	ABBAY			TUL	Nr. ADET	90	TULNr. ADET
122	*ABBAY*			*WENCHIT*	*Nr. ALEM*	*4 091*	*WENCHITNr. ALEM*
123	ABBAY			DIRMA	Nr. KOLA		DIRMANr. KOLA
124	ABBAY			SHEGEZ	Nr. ADET		SHEGEZNr. ADET

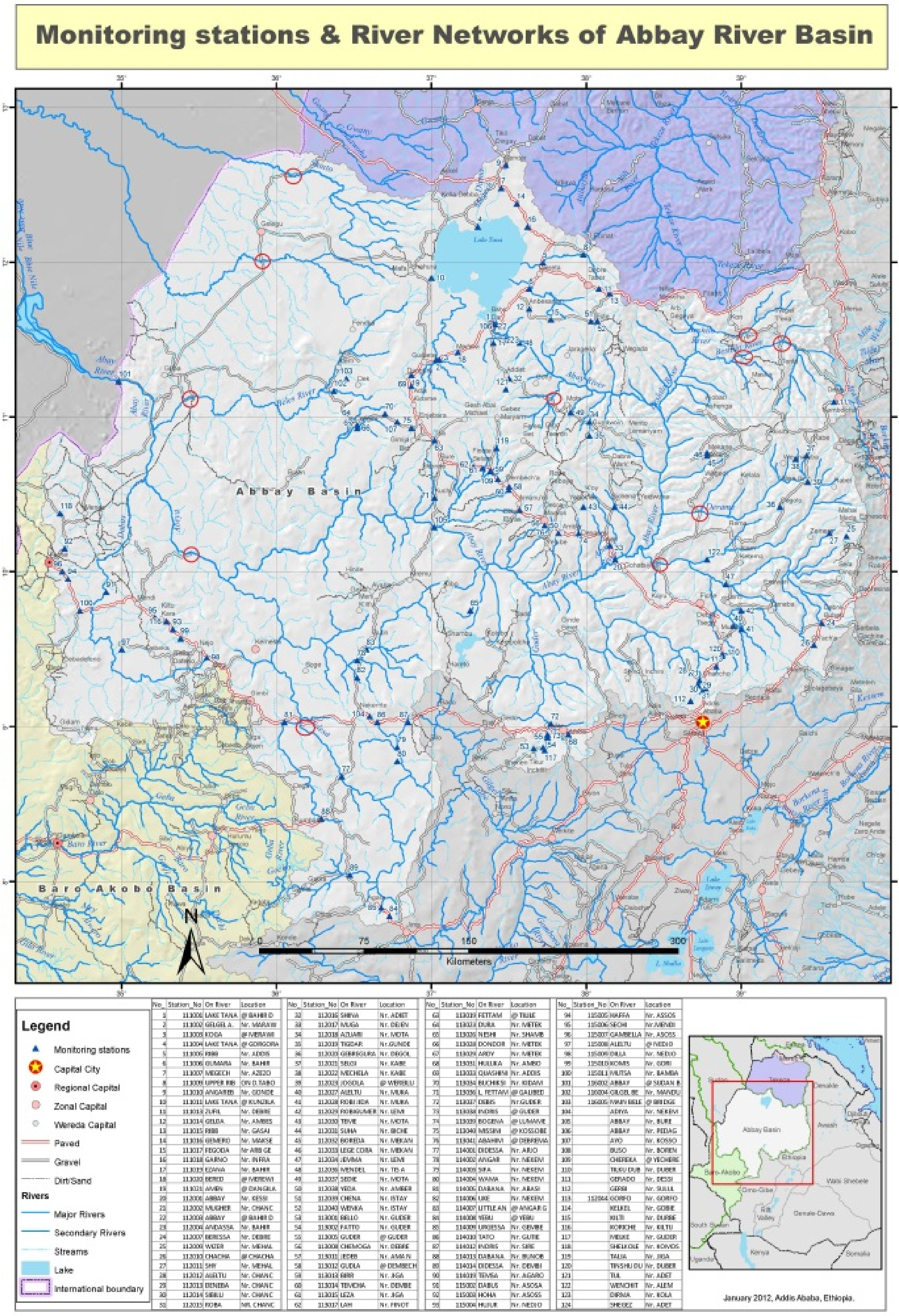


Figure 8 Ten potential new station locations in Abbay catchment, with present road access.

Tekeze Basin

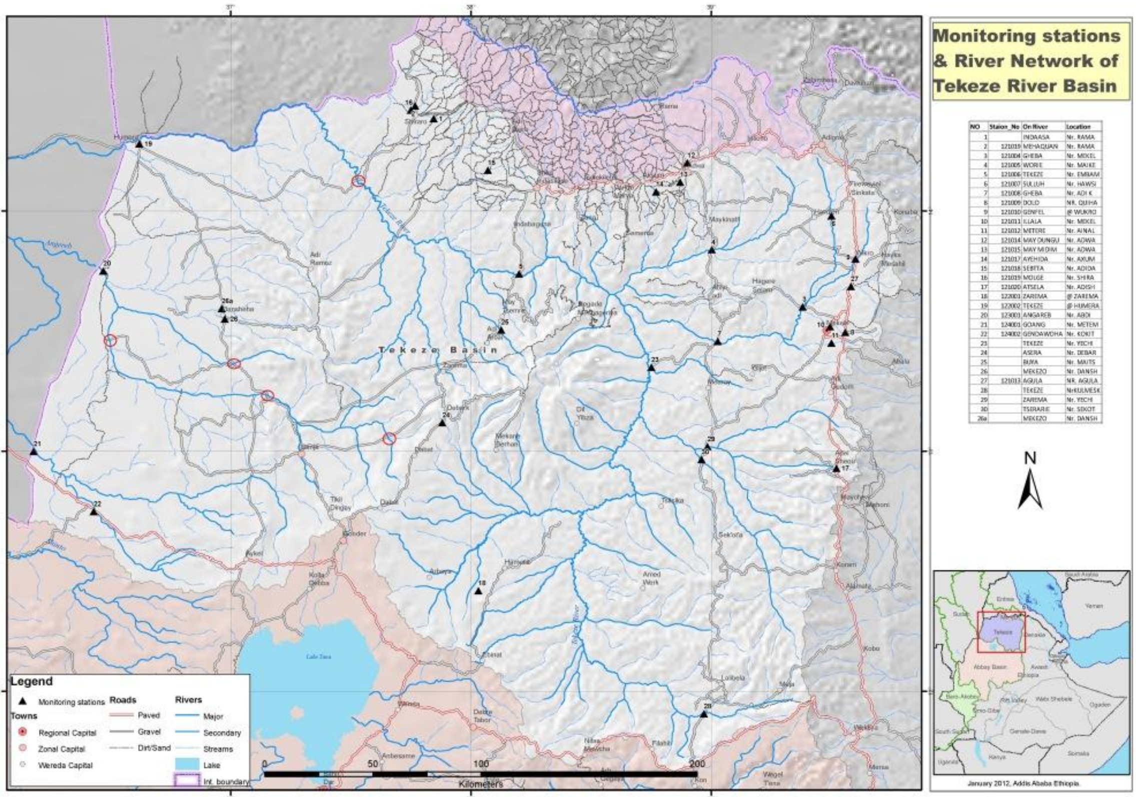
Here the principles are the same as for Abbay Basin.

There are presently approximately 31 monitoring stations in the Tekeze Basin. Of these, 21 should be kept as year round measuring stations, 10 stations should be either discontinued or evaluated for downgrading.

A total of 5 potential new station locations have been identified in the Western part of the Tekeze basin. All of these appear to have good road access. These 5 road crossing locations were selected where the potential station catchment is considerable or interesting for sediment monitoring. The total number of measuring stations in the Tekeze Basin would then be 26 instead of the present 31. There are tributaries in the Upper Tekeze catchment that lack monitoring, but none have been marked here because it is very doubtful if access could be provided at a reasonable cost.

At the same time as the number of stations is reduced, the frequency of discharge and sediment measurements should be increased substantially.

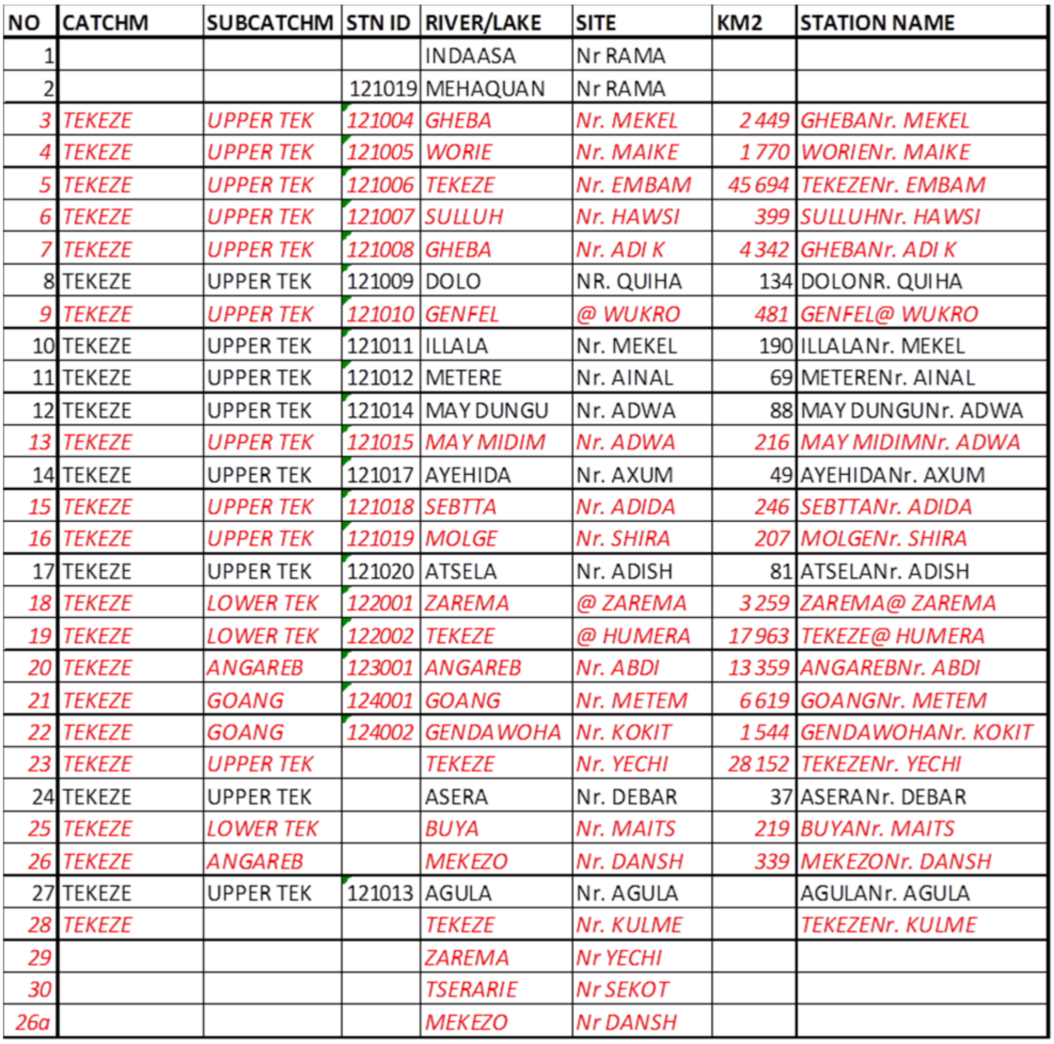
The exact locations of the stations to be kept need to be reviewed to make sure the cross section is acceptable for monitoring, otherwise, the station should be shifted to nearest suitable location. An example is Station 23, located immediately downstream of the Tekeze Dam. It is unnecessary to measure the flow downstream of a power station, as the flow through the station is well known or can easily be calculated from data available at the station. It is, however, of interest to measure the sediment content downstream of the station, so this measurement should be kept. It is recommended totest a new technology, the application of Laser to determine sediment concentrations, see e g Karki (2006). The station in general, including measurements of discharge, water level and sediment should be shifted to upstream of the reservoir. This may not be so straight forward if road access is poor. When the sedimentation of the Tekeze reservoir is assessed by bathymetric surveys, the analysis of sedimentation may be combined with analyses of the inflow of sediment in the new Station 23 and the outflow of sediment from the dam.



NO	Staion_No	On River	Location
1		INDAASA	Nr. RAMA
2	121019	MEHAQUAN	Nr. RAMA
3	121004	GHEBA	Nr. MEKEL
4	121005	WORIE	Nr. MAIKE
5	121006	TEKEZE	Nr. EMBAM
6	121007	SULUH	Nr. HAWSI
7	121008	GHEBA	Nr. ADI K
8	121009	DOLO	NR. QUIHA
9	121010	GENFEL	@ WUKRO
10	121011	ILALA	Nr. MEKEL
11	121012	METERE	Nr. AINAL
12	121014	MAY OUNGU	Nr. ADWA
13	121015	MAY MEDIM	Nr. ADWA
14	121017	AYEHIDA	Nr. AXUM
15	121018	SEBTTA	Nr. ADIDA
16	121019	MOLGE	Nr. SHIRA
17	121020	ATSELA	Nr. ADISH
18	122001	ZAREMA	@ ZAREMA
19	122002	TEKEZE	@ HUMERA
20	123001	ANGAREB	Nr. ABDI
21	124001	GOANG	Nr. METEM
22	124002	GENDAWOHA	Nr. KOKIT
23		TEKEZE	Nr. YECHI
24		ASERA	Nr. DEBAR
25		BUYA	Nr. MAITS
26		MEKEZO	Nr. DANSH
27	121013	AGULA	NR. AGULA
28		TEKEZE	NrKULMESK
29		ZAREMA	Nr. YECHI
30		TSERARIE	Nr. SEKOT
26a		MEKEZO	Nr. DANSH

Figure 9 Five potential new station locations in Tekeze catchment, with present road access.

Table 3 *Monitoring stations in Tekeze Basin. Stations in red Itallics are the stations proposed to be continued.*



NO	CATCHM	SUBCATCHM	STN ID	RIVER/LAKE	SITE	KM2	STATION NAME
1				INDAASA	Nr RAMA		
2			121019	MEHAQUAN	Nr RAMA		
3	*TEKEZE*	*UPPER TEK*	*121004*	*GHEBA*	*Nr. MEKEL*	*2 449*	*GHEBANr. MEKEL*
4	*TEKEZE*	*UPPER TEK*	*121005*	*WORIE*	*Nr. MAIKE*	*1 770*	*WORIENr. MAIKE*
5	*TEKEZE*	*UPPER TEK*	*121006*	*TEKEZE*	*Nr. EMBAM*	*45 694*	*TEKEZENr. EMBAM*
6	*TEKEZE*	*UPPER TEK*	*121007*	*SULLUH*	*Nr. HAWSI*	*399*	*SULLUHNr. HAWSI*
7	*TEKEZE*	*UPPER TEK*	*121008*	*GHEBA*	*Nr. ADI K*	*4 342*	*GHEBANr. ADI K*
8	TEKEZE	UPPER TEK	121009	DOLO	NR. QUIHA	134	DOLONR. QUIHA
9	*TEKEZE*	*UPPER TEK*	*121010*	*GENFEL*	*@ WUKRO*	*481*	*GENFEL@ WUKRO*
10	TEKEZE	UPPER TEK	121011	ILLALA	Nr. MEKEL	190	ILLALANr. MEKEL
11	TEKEZE	UPPER TEK	121012	METERE	Nr. AINAL	69	METERENr. AINAL
12	TEKEZE	UPPER TEK	121014	MAY DUNGU	Nr. ADWA	88	MAY DUNGUNr. ADWA
13	*TEKEZE*	*UPPER TEK*	*121015*	*MAY MIDIM*	*Nr. ADWA*	*216*	*MAY MIDIMNr. ADWA*
14	TEKEZE	UPPER TEK	121017	AYEHIDA	Nr. AXUM	49	AYEHIDANr. AXUM
15	*TEKEZE*	*UPPER TEK*	*121018*	*SEBTTA*	*Nr. ADIDA*	*246*	*SEBTTANr. ADIDA*
16	*TEKEZE*	*UPPER TEK*	*121019*	*MOLGE*	*Nr. SHIRA*	*207*	*MOLGENr. SHIRA*
17	TEKEZE	UPPER TEK	121020	ATSELA	Nr. ADISH	81	ATSELANr. ADISH
18	*TEKEZE*	*LOWER TEK*	*122001*	*ZAREMA*	*@ ZAREMA*	*3 259*	*ZAREMA@ ZAREMA*
19	*TEKEZE*	*LOWER TEK*	*122002*	*TEKEZE*	*@ HUMERA*	*17 963*	*TEKEZE@ HUMERA*
20	*TEKEZE*	*ANGAREB*	*123001*	*ANGAREB*	*Nr. ABDI*	*13 359*	*ANGAREBNr. ABDI*
21	*TEKEZE*	*GOANG*	*124001*	*GOANG*	*Nr. METEM*	*6 619*	*GOANGNr. METEM*
22	*TEKEZE*	*GOANG*	*124002*	*GENDAWOHA*	*Nr. KOKIT*	*1 544*	*GENDAWOHANr. KOKIT*
23	*TEKEZE*	*UPPER TEK*		*TEKEZE*	*Nr. YECHI*	*28 152*	*TEKEZENr. YECHI*
24	TEKEZE	UPPER TEK		ASERA	Nr. DEBAR	37	ASERANr. DEBAR
25	*TEKEZE*	*LOWER TEK*		*BUYA*	*Nr. MAITS*	*219*	*BUYANr. MAITS*
26	*TEKEZE*	*ANGAREB*		*MEKEZO*	*Nr. DANSH*	*339*	*MEKEZONr. DANSH*
27	TEKEZE	UPPER TEK	121013	AGULA	Nr. AGULA		AGULANr. AGULA
28	*TEKEZE*			*TEKEZE*	*Nr. KULME*		*TEKEZENr. KULME*
29				*ZAREMA*	*Nr YECHI*		
30				*TSERARIE*	*Nr SEKOT*		
26a				*MEKEZO*	*Nr DANSH*		

Baro Akobo Basin

Also here the principles are the same as for Abbay Basin.

There are presently approximately 27 monitoring stations in the Baro Akobo Basin. Of these, 11 should be kept as year round measuring stations, 16 stations should be either discontinued or evaluated for downgrading.

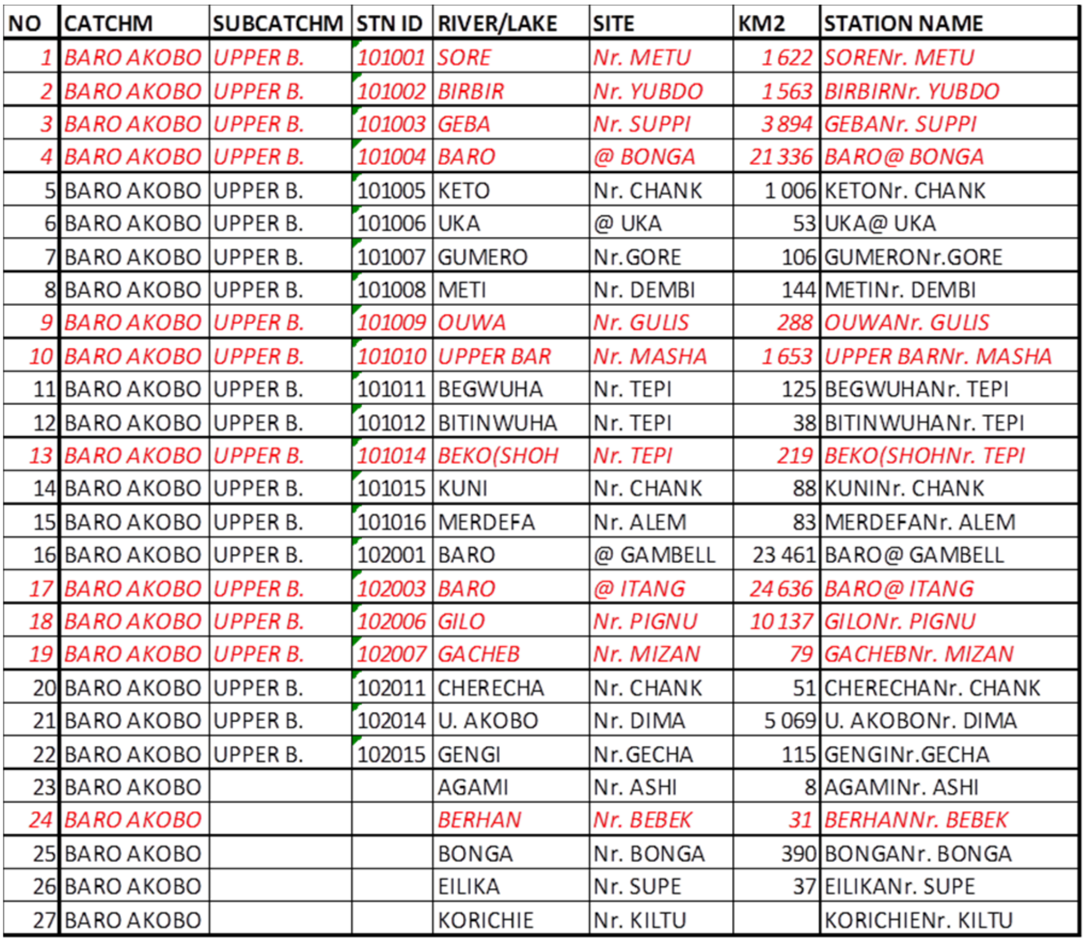
Of the 11 stations to be kept, stations 19 and 24 have small station catchments but in one of the areas with the estimated highest soil erosion in the basin. It is recommended that the sediment measurements for these stations are reviewed and a decision is taken on the usefulness of them. If there are not sufficient sediment data available, measurements are intensified over a few years in order that a decision can be taken.

A total of 5 potential new station locations have been identified. With planned new roads under design or construction, there are 5 new potential gauging stations that will now have road access, locations are shown in Figure 10. All 3 potential new stations are close to the border with South Sudan. It is recommended that it is agreed with Sudan to have just one station at the border that is monitored jointly between the two countries. If these 5 additional stations are implemented, the total number of measuring stations in the Baro Akobo Basin would then be 16 instead of the present 31.

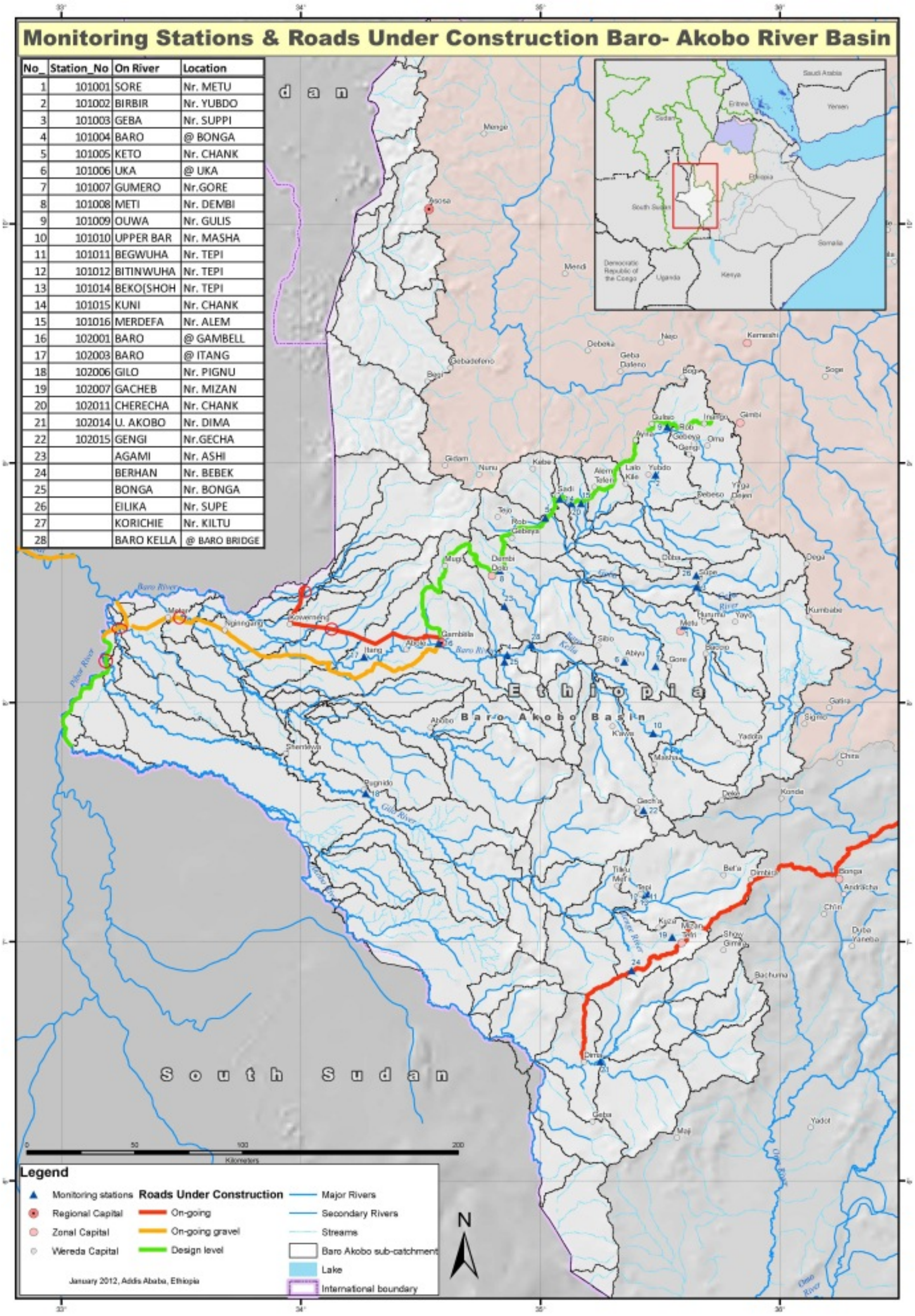
At the same time as the number of stations is reduced, the frequency of discharge and sediment measurements should be increased substantially.

The exact locations of the stations to be kept need to be reviewed to make sure the cross section is acceptable for monitoring; otherwise, the station should be shifted to nearest suitable location.

Table 4 Monitoring stations in Baro Akobo Basin. Stations in red Itallics are the stations proposed to be continued.



NO	CATCHM	SUBCATCHM	STN ID	RIVER/LAKE	SITE	KM2	STATION NAME
1	*BARO AKOBO*	*UPPER B.*	*101001*	*SORE*	*Nr. METU*	*1 622*	*SORENr. METU*
2	*BARO AKOBO*	*UPPER B.*	*101002*	*BIRBIR*	*Nr. YUBDO*	*1 563*	*BIRBIRNr. YUBDO*
3	*BARO AKOBO*	*UPPER B.*	*101003*	*GEBA*	*Nr. SUPPI*	*3 894*	*GEBANr. SUPPI*
4	*BARO AKOBO*	*UPPER B.*	*101004*	*BARO*	*@ BONGA*	*21 336*	*BARO@ BONGA*
5	BARO AKOBO	UPPER B.	101005	KETO	Nr. CHANK	1 006	KETONr. CHANK
6	BARO AKOBO	UPPER B.	101006	UKA	@ UKA	53	UKA@ UKA
7	BARO AKOBO	UPPER B.	101007	GUMERO	Nr.GORE	106	GUMERONr.GORE
8	BARO AKOBO	UPPER B.	101008	METI	Nr. DEMBI	144	METINr. DEMBI
9	*BARO AKOBO*	*UPPER B.*	*101009*	*OUWA*	*Nr. GULIS*	*288*	*OUWANr. GULIS*
10	*BARO AKOBO*	*UPPER B.*	*101010*	*UPPER BAR*	*Nr. MASHA*	*1 653*	*UPPER BARNr. MASHA*
11	BARO AKOBO	UPPER B.	101011	BEGWUHA	Nr. TEPI	125	BEGWUHANr. TEPI
12	BARO AKOBO	UPPER B.	101012	BITINWUHA	Nr. TEPI	38	BITINWUHANr. TEPI
13	*BARO AKOBO*	*UPPER B.*	*101014*	*BEKO(SHOH*	*Nr. TEPI*	*219*	*BEKO(SHOHNr. TEPI*
14	BARO AKOBO	UPPER B.	101015	KUNI	Nr. CHANK	88	KUNINr. CHANK
15	BARO AKOBO	UPPER B.	101016	MERDEFA	Nr. ALEM	83	MERDEFANr. ALEM
16	BARO AKOBO	UPPER B.	102001	BARO	@ GAMBELL	23 461	BARO@ GAMBELL
17	*BARO AKOBO*	*UPPER B.*	*102003*	*BARO*	*@ ITANG*	*24 636*	*BARO@ ITANG*
18	*BARO AKOBO*	*UPPER B.*	*102006*	*GILO*	*Nr. PIGNU*	*10 137*	*GILONr. PIGNU*
19	*BARO AKOBO*	*UPPER B.*	*102007*	*GACHEB*	*Nr. MIZAN*	*79*	*GACHEBNr. MIZAN*
20	BARO AKOBO	UPPER B.	102011	CHERECHA	Nr. CHANK	51	CHERECHANr. CHANK
21	BARO AKOBO	UPPER B.	102014	U. AKOBO	Nr. DIMA	5 069	U. AKOBONr. DIMA
22	BARO AKOBO	UPPER B.	102015	GENGI	Nr.GECHA	115	GENGINr.GECHA
23	BARO AKOBO			AGAMI	Nr. ASHI	8	AGAMINr. ASHI
24	*BARO AKOBO*			*BERHAN*	*Nr. BEBEK*	*31*	*BERHANNr. BEBEK*
25	BARO AKOBO			BONGA	Nr. BONGA	390	BONGANr. BONGA
26	BARO AKOBO			EILIKA	Nr. SUPE	37	EILIKANr. SUPE
27	BARO AKOBO			KORICHIE	Nr. KILTU		KORICHIENr. KILTU



No_	Station_No	On River	Location
1	101001	SORE	Nr. METU
2	101002	BIRBIR	Nr. YUBDO
3	101003	GEBA	Nr. SUPPI
4	101004	BARO	@ BONGA
5	101005	KETO	Nr. CHANK
6	101006	UKA	@ UKA
7	101007	GUMERO	Nr.GORE
8	101008	METI	Nr. DEMBI
9	101009	OUWA	Nr. GULIS
10	101010	UPPER BAR	Nr. MASHA
11	101011	BEGWUHA	Nr. TEPI
12	101012	BITINWUHA	Nr. TEPI
13	101014	BEKO(SHOH	Nr. TEPI
14	101015	KUNI	Nr. CHANK
15	101016	MERDEFA	Nr. ALEM
16	102001	BARO	@ GAMBELL
17	102003	BARO	@ ITANG
18	102006	GILO	Nr. PIGNU
19	102007	GACHEB	Nr. MIZAN
20	102011	CHERECHA	Nr. CHANK
21	102014	U. AKOBO	Nr. DIMA
22	102015	GENGI	Nr.GECHA
23		AGAMI	Nr. ASHI
24		BERHAN	Nr. BEBEK
25		BONGA	Nr. BONGA
26		EILIKA	Nr. SUPE
27		KORICHIE	Nr. KILTU
28		BARO KELLA	@ BARO BRIDGE

Figure 10   Five potential new station locations in Baro Akobo catchment, with future road access. This catchment was the only one where new road plans provide opportunities for new stations.

7.4 Measuring Techniques

7.4.1 Water levels

Pressure gauges should be tested at selected key stations. The installation should be as robust as possible and well protected against vandalism. Staff gauges should be kept at all stations.

At key stations, more solid gauges should be set up. The stations belonging to the Egyptian Irrigation Department in Sudan may be taken as a model in some cases. At bridges where it is possible to mark gauge levels on bridge piers and abutments, then this should be done carefully. The primary staff gauge should be used for readings unless it is damaged. The suggestion by BRLi (2009) to equip staff readers with binoculars should be implemented where beneficial.

A dedicated effort should be made to get existing but not functioning radar and ultrasonic gauges to function. If, in that process, a suitable setup for a functioning system is identified, then such system may in some cases take preference over the pressure cell based gauges, especially at stations where there are suitable and well protected places to mount the equipment.

7.4.2 Discharge

The present propeller type flow measurements can be continued until better equipment/methodology is developed. At locations with very high flow it is recommended to calculate the discharge without the measurement closest to the bed, as instruments often get damaged in this lowest position.

ADCP technology should be used to measure discharges in key stations, probably also in other stations with time. The lessons learned in Sudan should be taken on board and a robust system implemented in Ethiopia. The cost doubles from the basic setup (ADCP and boat only) to the most advanced setup, which may be required in high sediment concentrations and movable bed (ADCP+GPS+Echosounder + boat). The optimal solution may well be to use the ADCP in 2-3 different setups, suitable to different stations at different seasons.

The promising new technology, Surface Velocity Radar (SVR), to measure surface velocities should be investigated further. It is used in combination with ground penetrating radar suspended above the water surface to survey the cross section profile. The major attraction about such setup is that no equipment is submerged in the flowing water.

7.5 Laboratory Facilities

Laboratory facilities and staffing that are sufficient to cope with the number of sediment samples to be analysed, shall be established. It is recommended to have one main laboratory, possibly supplemented by mobile field laboratories. In Ethiopia the main laboratory would be in Addis Ababa, in Sudan it would be in Khartoum or Wad Madheni.

The future sediment laboratory shall be able to determine:

a) Concentrations of suspended load

b) Grain sizes distribution of bed material

c) Grain size distribution of suspended load

Today, the laboratory in Addis Ababa does only a) by means of concentration analyses (by **filtering, drying and weighing**). That technique shall still be the most frequently used.

Grab samples (van Veen type) of bed material will be taken to the laboratory for **sieve analysis**, in case the bed material is sand or coarser.

Samples of suspended load (fines) may be analysed for grain size distribution, for instance **by pipette technique**, which is practical as it does not require the very large samples required for testing by for instance bottom withdrawal tube.

7.6 Data Analysis and Quality Assurance

Obligatory quality checks of all steps from data collection through processing to the final processed and analysed data are numerous and shall not be repeated here.

Other aspects of data quality assurance that is not in operation today are:

- Feedback from external users. It should be a condition for the external users that they, in return for the data provided, deliver their detailed report on how the data were used and their review of the data.
- Data quality check through use of modeling. When a model has been set up, the data should be entered into the model, and the model will link the measurements done at different stations and thereby provide an internal consistency check. This will apply to the hydrology in particular and also to some extent to sediments once a sediment model is set up.

8 Recommendation on Data Transfer

In this section, the data transfer that is considered is the transfer from the place it was measured/recorded to the receiving organisation where the data is processed, analysed and maybe used as a decision basis for some kind of action. System(s) to use for data transfer depend on the data and the purpose and urgency of the transfer.

Some information has little urgency, for instance sketches of the placement of a new staff gauge with coordinate of its position and level of gauge zero. But it is important this information is transferred wit the first set of data from that gauge. Daily water level readings during dry season may not be so urgent either, in particular when no discharge measurements are done at the station. In these cases, transfer of data at some months interval may be sufficient (manual transfer). In Ethiopia it has been customary to transfer gauge readings to Addis with Hydrology staff when they pass by the site at up to 3 months intervals. This may be sufficient for some types of data as the ones mentioned above, but not always.

During floods water levels vary fast and one measurement per day is no longer sufficient. It is also during the flood period that it is particularly important that discharge measurements are carried out frequently. It is important that data is transferred within, say, a few weeks in order to catch any errors or suspicious data that could be an indication of malfunction or a shifting of gauge zero etc. Land line telephone or cell phone is a suitable option for transfer of for instance daily data from a station to the receiving organisation. In order to avoid mistakes the same data may be transferred manually by carrier at some months interval. The figures can then be checked once the written data are received.

In river basins where downstream areas are prone to flooding or they need to be warned of sudden changes in conditions upstream for any other reason, it may be necessary to transfer the data fast and reliable. The ultimate automatic system would consist of automatic gauges with automatic transmission of the recorded data by satellite system to the data receiver for immediate analysis and dissemination. If fully automatic, the system must be equipped with alarms that detect abnormal behaviour and staff on duty to react on the alarms. Manual staff gauges should be available on these sites as a check of the automatic readings. Satellite communication is offered by satellite operators for satellites in geostationary orbit.

9 Databases

9.1 General

Electronic database systems have existed for several decades, and are generally developed to communicate quite smoothly between other database systems and to readily accommodate data of various standard formats. Which database system to use then becomes a secondary issue. The most important is which parameters are measured and which are stored in the database. It should be checked during database setup that unified definitions and units of parameters are used in EN countries, to avoid any confusion. And, unless the same system is implemented in all countries, the smooth exchange of data between the different systems should be checked.

The final decision on database system should be taken after considering the recommendations for the DSS presently being set up and even the application that with time will develop under the ENPM.

There will be different categories of data in the database:

a) Raw data
b) Processed data
c) Elaborated data
d) Metadata

It is crucial that each category of data is kept strictly separated from the other categories. To emphasize this, and to safeguard against any mixing, it is recommended that different staff are working on the different categories, a), b) and c). Each category would require special permission for any changes to be made.

Raw data entry and quality check for typing errors should be carried out as soon as possible after the data is received from the field. In case of any doubt about the interpretation of the data sheets received from the field, this should be clarified with the field team and a note be made about the interpretation. Once approved, the raw data should be locked for changes. Unlocking for any further changes should be possible only in very exceptional cases.

Processed data would involve some calculation to arrive at for instance the measured discharge, the measured sediment discharge, the water level according to some reference system. Once approved, after rigorous quality check, the processed data should be locked for changes. If, at a later stage, a justified change in the calculation method is made, the processed data can be unlocked and the change implemented and quality checked. It is important to note that elaborated data using the changed processed data will be outdated until they are updated.

Elaborated data would need the lowest degree of protection. Various sets of clearly documented elaborated data may be present in the database system. Only the person who created each set of elaborated data should have access to change this data. He can then give permissions to others.

Metadata is ‘data about data’ or ‘data about the containers containing data’. This is updated when new data is added.

Databases are one of the basic elements of the future monitoring system. When designing the databases it is important to bear in mind the objectives that the system shall be able to:

- Efficiently and securely store monitoring data (existing and future)
- Support data retrieval for various needs (including data needed for modelling)
- Enhance data sharing and support data dissemination

9.2 Inventory and Collection of Existing Data

When building a future database system, it is important to make a thorough inventory of existing data, since this will be the foundation on which the modifications of the future database will build. The existing software and data formats have to be specified and thoroughly documented. Presently, monitoring data are predominantly stored in Excel-files, some Access-files may exist. Reports are stored in Word-format. Drawings and maps are predominantly stored in CAD-files, some GIS ArcView exist.

It will be helpful to store all the existing data (from different departments and computers) in a filing system on one common platform under well documented catalogues, so that the database designers will have easy access to data of similar sort. The data has to be categorised in themes and identified as to their temporal and spatial distribution. Gaps have to be identified and documented. Such documentation should be stored in easily identified index files under the same catalogues as where the data is stored. Existing time series have to be scrutinised and documented in order to be able to combine with data with equal or similar time series. Data that has not been coded digitally has to be identified. Since the input needed in order to digitise such data usually is great, it is important to prioritise the data and start digitising the most important data early.

9.3 Specification of Data Base Entries, Planning of Database Setup

Database entries have to be planned carefully, taking into account many issues, such as:

- The need for thematic databases, well-structured in order to facilitate efficient data entry and retrieval
- The availability of index fields, common keys that can link different databases
- Data quality assurance built in, giving reasonable possibilities to validate data (data ranges allowed, default values, scroll lists etc.)

Data has to be categorised into fundamental database building stones, such as geographically oriented data that can be assigned a location or coordinate. Geographical data has to be treated separately if it refers to vector data (i.e. polygons, points and lines) or raster data (i.e. satellite images, aerial photos and/or scanned maps). Projections and coordinate systems have to be defined. The possibilities of linking general databases to a competent GIS (Geographical Information System) should be evaluated and built in as often as possible.

Database administration has to be planned carefully, especially since the project might anticipate data entry and data dissemination between different authorities.

- Security of the system must be guaranteed through user identification and password control (allowing “super-users”, “editors”, “read-only” but also adding possibility of treating selected data as restricted or sensitive to different users)
- Data backup routines must be planned carefully, putting demand on both hardware and software solutions (in order to retrieve a back-up section of the database from time before corruption)

Retrieval of data from the database has to be planned carefully with the stakeholders. A set of commonly needed queries and generated reports should be prepared. It might also be necessary to incorporate the possibility of more complex data retrieval, such as for input data for the modelling activities anticipated. Also results from modelling might form valuable data that should be stored again into the database. Routines for categorising and indexing such modelling results have to be prepared, so that also this data can become part of future queries.
Data dissemination has to be planned carefully, with dialogue between stakeholders and authorities. Depending on the outcome of these discussions and the consensus regarding the level of security and openness, it can be a good idea to facilitate database dissemination and possibly also data update through the internet. This puts further demand on hardware and software security with the need for password protection and firewalls etc.

One important issue regarding the needs of the future database is the necessity of being able to treat large amount of data entry in semi-automatic form, i.e. data-loggers representing frequent or continues registration or computerised monitoring equipment, possibly feeding the registered data on-line into the database. This calls for specifications of routines for downloading this data from the future hardware and possibly to filter the data to some degree (daily average values stored etc.)

A certain part of the database to be developed is a “Knowledge Database”. Presently, knowledge and information is available but scattered in many libraries and with individuals. The intention with the “Knowledge Database” is that much of the available information can be found here in digital form, and information on where to find other available knowledge. A “Knowledge Database” might contain digital reports or references to other reports and guidance to where they might be published or stored. Other example of data entries might be reference to people and capacities within different organisations, relevant to the Lake Management.

An example of the future database design and its components and relationships is shown in Figure 11.

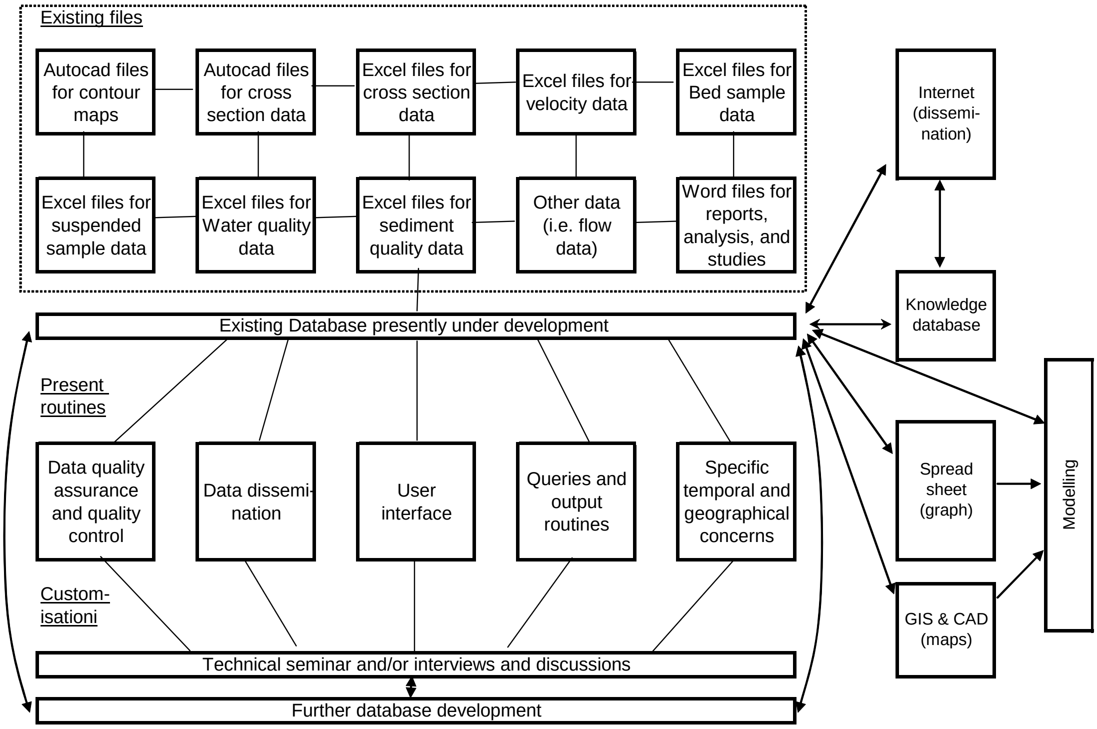


Figure 11 An example of the future database design and its components and relationships

9.4 Database System

It is recommended that the database system should be the system presently under development under the Nile Basin DSS Project. Any intermediate database systems should be compatible with this system.

9.5 Guideline and Training

Any database has to be thoroughly documented. It is important to plan for this documentation early when designing the database. The database should be developed to cater for data from the existing monitoring system and is also meant to take in data from the future updated and monitoring system. This means that the development of the database will take place over some time and implies that the documentation has to be in form of a living document that can be updated under duration of database development.

Training in use and management of the database is a crucial component. It is particular important to build this capacity within the organisation(s) that own the database. But also the external organisations that will feed data into the database or benefit from data dissemination need a certain level of training. A substantial part of training of the system will should be done as on-the-job training while developing the database. It is important to plan for building capacity with more than one person in each organisation in order not to become vulnerable and dependant on one person alone. The documentation of the database development will become important guidelines regarding future management routines and training. Formal training will have to take place among all researchers and users of the future database.

10 Design of Basin-Wide Monitoring System

The design of a monitoring system in a river basin is based on the answers to the following questions, posed along a time-line to reflect different stages. Stages are names in a terminology with its origin in structural design projects.

Design Basis
1. What are the purposes of the monitoring?
2. What information is needed from each river/tributary (may vary)?
3. With which frequency is this information needed during different seasons?
4. With which accuracy?
5. How urgent is it needed? (real time or allow for transfer and processing)

Conceptual Design
6. What are the alternative technical solutions?
7. Compare and do preliminary selection, cost estimate and implementation schedule

Detailed Design
8. Where exactly do we measure? (site visits)
9. Adapt technical solution to each site.
10. Final cost estimate and implementation schedule

Tendering
11. Tender documents
12. Evaluation of bids

Supervision
13. Supervision of implementation
14. Supervision of testing

It is important and maybe surprising to realise that the answers belonging under the first stage, those that should be used to form a basis for the design, are not available. Monitoring systems exist, but there is no clear formulation of the basis for this monitoring. Even the purposes are usually not clear.

This means a design would have to start almost from scratch and take its starting point in a discussion of why monitoring is required, what information is required etc.

The divide between Conceptual and Detailed Design is important. At the completion of a Conceptual Design, all main principles of the design is ready; a number of “station types” may have been set up. These principles can then be agreed before proceeding to the Detailed Design, where station types are distributed within the river system and adapted to each selected station location.

Water level gauging is the backbone of the monitoring. Even though experience has shown that auto-gauges do not work, one or a few reliable gauge types should be selected based on detailed testing for robustness and reliability. Implementation which should begin in key stations should be done after it has been ascertained that the gauges will work. Existing staff gauges should be kept at those stations as back-up. The types of auto-gauges to test are radar or ultra-sonic and pressure cell type gauges. In stations with manual record of data, water levels should be read/recorded at least daily, with more frequent readings during the flood season. The reading frequency should be determined individually for each station, based on the variability of the flow, as recorded in historical data.

Discharge measurements should be continued using the traditional and established methodology, using a current meter in a number of verticals in each cross section. When the velocity is very high and the risk of damage to the current meter during measurement close to the bed (Ethiopia), measurement in the point closest to the bed should be omitted and the calculation revised to that effect. More importantly, the entry of new technologies for measuring river discharge which has begun slowly should be stimulated. A few different ADCP configurations (with or without DGPS and Echo-sounder) should be established after proper testing, with the aim of using the ADCP in all key stations. Surface Velocity Radar (SVR) should be tested and if the tests turn out positive, be applied to measure discharges at peak floods where the use of other methods are difficult or impossible. After comparison with other methods it may be used instead of other methods, if the accuracy is found to be satisfactory. The aim is to obtain more reliable data more efficiently.

No general guidance is provided on the frequency of discharge measurements, but as a general rule, there should be a sufficient number of discharge measurements carried out each flood season, so as to be able to decide if the rating curve has shifted or not. A sufficient number of measurements have to be done, but even more importantly, the measurements should cover a wide range of flows. A decision on the actual shift of the rating curve may not be done until after one more season of measurements.

Depth integrating sampling technique should be used for measuring the suspended sediment transport. No bed load measurements should be done, since this is too inaccurate and requires extreme care. But at locations where it is justified (based on historical data) that bed load constitutes a significant portion of the total transport, bed material samples should be taken for grain size analysis every time sediment transport measurements are carried out. Information from these shall then be used to calculate the bed load. Generally, sediment measurements shall be done in all stations where discharge is measured (Q-stations), but the frequency of sediment measurements may differ from the frequency of discharge measurements. The reading frequency should be determined individually for each station, based on the variability of the flow, as recorded in historical data.

It is only very recently, that modern high-tech methodologies have entered the field of sediment transport measurements. One is the use of ADCP backscatter, which does not seem to be widely used in rivers yet (Ghaffari, P. et al. 2011). Another promising advanced method of measuring both suspended sediment concentration and grain size distribution is based on laser diffraction technique, a method that has now been endorsed by the the USGS, ref. Andersson (2010). For equipment and further description including scientific papers, see the web-site of Sequoia Scientific, Inc.:

http://www.sequoiasci.com/products/Suspended.aspx

Their LISST instruments are designed for use in hydropower plants, but with possibilities to be used also in sediment measurements in rivers. The instrument that will work with concentrations up to 20-30 g/l is the LISST-Infinite. It is, however, designed to be connected to a PC for continuous monitoring of sediment concentration and size and requires 110 or 220 V AC (personal communication, Dr Ole Mikkelsen, Vice President, Sales, Sequoia)

http://www.sequoiasci.com/products/SedimentSensorHydroPower.aspx

Very comprehensive guidelines on the design of monitoring networks are given by the Hydrology Project (1999, 2001, 2003). Reference is made to a few of the manuals issued by this project, but many more are freely available from their web-site http://www.hydrology-project.gov.in/manuals_n.asp. It is recommended that these guidelines are used in EN countries. They are made for the Indian sub-continent, but are so general that they would apply to EN countries as well.

11 Guideline on a Harmonization of Standards and Methods on Data Collection and Quality Check

As described in Chapter 9, the setup of a common database will ensure that all types of data, collected in all countries, will fit into the database. The database will have its requirements on data formats, parameters and also contain all necessary explanations to accompany different parameters and different measuring methods. The purpose of a harmonization is to be able to smoothly share data between EN countries, without the risk of misinterpretations and mismatches. The database structure presently under implementation through the Nile Basin DSS project will ensure harmonization of standards and methods.

It is recommended that all EN countries follow the standards set up under the DSS project. In order to ensure uniformity in in the data sets it is further recommended that data are collected following relevant WMO Standards, and using SI units. A common data quality assurance should be established for each data type, similarly in all countries. It is presently uncertain to what extent this is taken into consideration in the Nile Basin DSS project.

Different methodologies have been discussed in preceding chapters, outlining a number of basic principles to apply with the aim to obtain high quality data as efficiently as possible. For instance, it is recommended to set up mathematical models to assist in quality assurance and even to assist in making the monitoring effort as efficient as possible.

12 Recommendation on Institutional Setup

Recommendations on the institutional setup have been made chapter 7. The present chapter provides the basic principles.

Increasing development in the EN catchments increase the need and the large benefit of a quality monitoring network for hydrology and sediment, with the benefits enhanced by mathematical modelling.

The modelling will link the disciplines of meteorology and hydrology/sediment, and will require close collaboration between hydrologic and meteorological monitoring. Linking the two disciplines by placing them institutionally under the same umbrella will be beneficial for several reasons.

The monitoring efforts should be reviewed to establish a vision for the future and realistic goals for the coming years. When the ambition level is decided, a detailed design of the monitoring network may be done to fit the set goals.

Monitoring of many different parameters should be well coordinated. A coordinator should be appointed, who has overall responsibility and full overview over all monitoring efforts.

In Ethiopia, the establishment of River Basin Authorities (RBAs) are underway. It is recommended to consider carefully before moving presently centralised functions to the RBAs. Overall planning of monitoring, data processing and storage in database should be kept at central level.

In Sudan, the MoIWR has historically been responsible for monitoring, although several other institutions are involved and do their own monitoring. It is important that one institution clearly has the main responsibility for setting the standards and coordinating the efforts. It would be logical that MoIWR takes this responsibility, but it is important that they are given the economic means of fulfilling this duty.

Good data is worth a fortune and collecting the data is costly. How to cover the cost of setting up and operating a high quality monitoring network is a question for politicians to answer.

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Annex 1: Identification and quantification of sediment sources by detailed remote sensing analysis combined with radioactive Caesium detection method

The sediment yield of a river is dependent on available sediment in the river channel itself, supplied by bank erosion and supplied from the surrounding catchment areas. To reduce the sediment load the normal procedure is to apply soil conservation measures reducing the sediment input from the catchment areas as supplied by sheet and gully erosion. Soil conservation measures (terracing, tree planting, etc.) is costly and needs, at least initially, to be focussed on the most important areas in order to radically reduce the sediment transport and the sedimentation hazards of reservoirs.

Soil loss equations (USLE and others) are developed for agricultural purposes and give a theoretical but imprecise answer to the question of sediment sources as they do not take into account that the sub-catchment considered is not in balance morphologically. Short-term storage and erosion within the river cross section can be significant contributions in the sediment balance and even a long-term morphological trend may contribute.

By applying remote sensing of Spot images with high resolution, eroded areas will be identified by supervised digital classification of image data. Visual interpretation of images can, by applying standard procedures developed classify the erosion type and intensities according to an ordeal scale. The main purpose of the remote sensing analysis is, however, the identification of main sediment sources, rather than the quantification of the erosion. The sites thus identified by remote sensing can subsequently be used to quantify erosion by applying a radioactive Caesium technique.

This method has been widely used and proven to be reliable in different parts of the world (Walling and Quine, 1992; Kulander, 1989). The technique is based on measurements of Caesium fallout (Cs-137) from nuclear weapon tests. Following nuclear weapon tests, a layer of Caesium spread over the world via the stratosphere before precipitating somewhat evenly over the ground (Walling and Quine, 1992; Kulander and Strömquist 1989).

The method assumes even regional fallout and is, in essence, a comparison of the amount of Caesium in soil layers. Using a reference area where no erosion has occurred, the history of soil erosion can be studied. Low Caesium content is to be expected in areas with steep slopes as opposed to an accumulation of Caesium in plateaus and valleys.

Analysis of the Caesium content of soil samples will be required, for instance by the laboratories at the Geography Department at University of Exeter, UK, which is a leading facility to analyse Cs with regards to quantification of soil erosion.

The field sampling for caesium testing can at the same time serve as ground verification for the remote sensing analysis.

Annex 2: Bathymetric Surveys

Table of Contents

1. Basic principles

This section mainly addresses the bathymetric or underwater field survey process, but it is even possible to combine with land survey of not-submerged parts of a reservoir. The term:

"bathymetric survey" specifically refers to the collection of water depths, while the broader term

"hydrographic survey" refers to a survey, including the above and below water portions. The even broader term

"reservoir survey" may be used to indicate a variety of field observations and measurements, data processing, analyses, and report preparation.

The above water portion of the reservoir can be measured by several means. Conventional surveying techniques using rods, transits, total stations and global positioning systems (GPS) can be used, along with photogrammetric mapping or aerial surveying (LIDAR), which provides more automated means for above water surveys.

Reservoir sedimentation can remain invisible for a significant portion of the life of a reservoir. However, lack of visual evidence does not reduce the potential impacts of reservoir sedimentation on functional operation of a reservoir.

The sediment deposition process in reservoirs generally follows the same basic pattern, with coarser sediments settling first in the upper reservoir area as the river inflow velocities decrease, forming a delta. Deposition continues from upstream to downstream, with the sediment gradation becoming finer as the deposition progresses towards the dam until the inflowing sediment is deposited throughout the length of the reservoir. Some of the inflowing fine sediments (silts and clays) typically stay in suspension and may discharge through the dam outlets or spillways. As sediments deposit near the dam outlets, they eventually will be discharged downstream as releases are made from the dam.

The primary objective of a reservoir survey is to measure the current reservoir capacity. The main cause of storage capacity change is sediment deposition - or erosion. Typical results from reservoir survey data collection and analysis include measured sediment deposition since dam construction and since previous surveys, sediment yield from the contributing drainage, and future storage-depletion trends. Survey results can reveal the distribution of deposited sediment (laterally and longitudinally). The density of deposited material, if required, may be determined by sampling. The results of the surveys can be used to determine the reservoir trapping efficiency and for evaluation of the reservoir operation.

Usually, the sedimentation will first appear as the formation of a delta at one or more inflow points of the reservoir, but eventually the inflowing sediments can deposit throughout the reservoir. Full coverage may require both above and below water measurements that significantly increase the field collection time and cost. It is therefore recommended that only bathymetric surveys are done when the reservoir is as full as possible, i.e. the measurements are only under water.

2. Survey frequency and schedule

The schedule and frequency of conducting reservoir surveys should depend on the estimated rate of reservoir sediment accumulation, along with the current operation and maintenance plan.

However, the current need to address site-specific problems, along with available funding, usually determines if and when a survey is conducted. The frequency of resurveys may depend on the estimated rate of sediment accumulation in the reservoir. For example, some have used a 7.5-percent storage reduction between surveys or a 5 to 10-year interval.

Some reservoirs in are relatively small in size, which can be surveyed with small vessels. Modern survey equipment can be more easily adapted for the smaller vessels. When available, an enclosed cabin on the survey vessel is a desirable option that protects the crew and equipment, and it allows surveys to be conducted safely throughout the year. Equipment can also be purchased that is weather proof, allowing open boat data collection in most weather conditions. Today’s equipment has minimized the effect of rough water on data accuracy, but its effect on the collection crew must be considered. Although a nearly full reservoir during a non-rainy season is the best condition for conducting a reservoir survey, the equipment and survey vessel should be set up to cope with all conditions, since they can change at any time.

Other means of determining frequency of reservoir sediment surveys include measured sediment inflow rates from previous surveys and sediment records from inflow streams. In general, larger reservoirs require less frequent resurveys. More frequent surveys are usually required if reservoirs are operating under conditions of greater risk, such as flood control or water supply storage, or if located in metropolitan areas. An additional factor in the survey schedule is the inflow of unconsolidated material that may create a soft reservoir bottom and erroneous echo sounder depths. With such softer bottom a sounder with lower frequency echo may be required. The lower frequency echo sounders can penetrate the soft layer and provide depths to the harder bottom, but these depths could be somewhat subjective to what the true bottom is. It would be best to avoid such conditions, but for some reservoirs, these soft bottom reservoir conditions always exist. It is presently not known if such conditions exist in reservoirs in EN countries. It is suggested that the first surveys are analysed carefully to assess if soft bottom reservoirs are giving problems in the monitoring using the available equipment. Echo sounder depths should be confirmed by manual measurement, despite the extra cost. However, manual measurements are somewhat subjective to individual judgment and are difficult in deeper reservoirs.

3. Position data

The extent of data collection is determined by the need of the data, reservoir conditions, cost of collection and analysis, and capability and limitations of the collection system. Typically, the GPS horizontal positions can be updated once per second, a single beam electronic depth sounder can provide continuous output of 20 or more depths per second. Filtering of the data that may be necessary for final computations should be conducted during data post-processing.

The chief surveyor must understand the goals of the study and must determine the data density to meet the goals within available budget.

The use of a multi-beam collection system provides the capability of full bottom coverage of the underwater reservoir areas, but it requires more time for collection and analysis than many budgets will allow. The multiple-transducer and multibeam collection systems can provide 100-percent coverage that removes the unknowns between the survey line spaces, but the costs and operation of such systems are more difficult to justify. At present it is not recommended to use multi-beam echo-sounder for routine reservoir surveys in EN countries. This more advanced instrument may, however, be used by other agencies in their special studies of sedimentation in the larger reservoirs.

Survey productivity has increased by a factor of 75 since the 1960s and a factor of 10 since the1990s, USACE, 2004, Ref /9/. The productivity increases are mainly related to electronics and computer development.

There are several versatile software packages capable of simultaneously receiving data from multiple devices during collection and processing the collected data. Some options include collection, post-processing, and editing of single and multi-beam data, geodesy transformations and volume computations.

The positioning equipment for bathymetric surveys has varied over time, with the latest major change for measuring horizontal positioning being GPS. The GPS is a very versatile instrument for measuring horizontal positions, which although relatively new and still undergoing technological advancements, is more accurate and less costly to operate than previously used conventional survey methods and has been rapidly integrated into bathymetric survey setups.

The GPS receivers use satellites as reference points for triangulating their position on earth from distance measurements to the satellites. A minimum of four satellite observations is required to mathematically solve for the four unknown receiver parameters (latitude, longitude, altitude, and time). The time unknown is caused by the clock error between the expensive satellite atomic clocks and the imperfect clocks in the GPS receivers. For bathymetric surveying, the water surface elevation parameter would usually be measured by means other than GPS. This means that only three satellite observations are theoretically needed to track the survey vessel. However, to obtain the most highly accurate position, the survey vessel GPS receiver tracks all available satellites.

There are two basic operation methods to obtain GPS positions: absolute and differential. Absolute positioning normally involves only a single GPS receiver and is not accurate enough for use in most hydrographic positioning. A single GPS receiver's absolute position is not as accurate as it appears in theory because of range measurement precision and the geometric position of the satellites. Due to these factors, estimated absolute real-time position accuracies of only 10 to 16 meters are common. The absolute mode for positioning does not provide sufficient positional accuracy or precision for the majority of many bathymetric surveys. The error sources can be eliminated or minimized by using Precision Positioning Units or differential GPS techniques.

The GPS satellites provide two levels of navigation services: Standard Positioning Service (SPS) and Precise Positioning Service (PPS). SPS receivers use available GPS information broadcast to anyone in the world, but security devices such as the anti-spoofing (AIS) factor guard against fake transmission data by encrypting the P code with a classified Y code denying the SPS user the higher P code accuracy. Precise Positioning Service is an accurate worldwide positioning technique available to the US military, and not an option for bathymetric surveys in EN countries.

Prior to GPS, most bathymetric surveying operated with a horizontal accuracy of 2 to 5 meters. Most studies now are calling for much greater accuracies and require the use of systems such as differential GPS (DGPS). Differential positioning requires at least two receivers and can provide precisions necessary for real time hydrographic surveying. One method of collection to resolve or cancel the inherent errors of GPS (satellite position or SIA, clock differences, atmospheric delay, etc.) is called differential GPS. Differential surveying is the positioning of one point in reference to another.

The basic principle is that errors calculated by multiple GPS receivers in a local area would all have common vectors. DGPS determines the position of one receiver in reference to another and is a method of increasing position accuracies by eliminating or minimizing the uncertainties.

Differential positioning is not concerned with the absolute position of each unit, but with the relative difference between the positions of two units simultaneously observing the same satellites. The inherent errors in satellite positions and atmospheric delays are mostly cancelled because the satellite transmission is essentially the same at both receivers. The method includes setting one receiver over a known geographical benchmark programmed with known coordinates. This receiver, known as the master, base, or reference unit, remains over the known benchmark, monitors the movement of the satellites, and calculates its apparent geographical position by direct reception from the satellites. The inherent errors in the satellite position are determined relative to the master receiver's programmed position, and the error corrections or differences are applied to the mobile GPS receiver on the survey vessel.

The attainable accuracies using differential survey techniques usually depend on the grade or cost of the GPS receivers. The average grade-mapping receivers that determine differential positions can obtain accuracies of 2 to 5 meters. Although even higher accuracy might be desirable and also possible by use of so-called RTK DGPS

(RTK=Real Time Kinematics), cost and time comes into consideration here. It is recommended that the accuracy associated with a conventional DGPS system is considered satisfactory for the reservoir surveys in EN countries. The obtained accuracy will have to be taken into consideration in setting the frequency of the surveys and in the sedimentation rates derived from the surveys.

During post-processing DGPS, the master and mobile GPS receivers record satellite tracking observations simultaneously as standalone units with no active data links between them. The master station is located at a known datum in the study area, or a community GPS base station is used. Differential correction software is used at a later time to combine and process the collected data. With this method, the mobile GPS receiver will be in the absolute mode and provide erratic positioning and tracking information during the time of collection.

4. Bed level data

The preferred option will be to use an echo-sounder to record water depth, and with a known vertical position of the transmitter, the level of the reservoir bed. Sounding devices for depth measurement has been widely used for bathymetric surveys over the last 50 years.

Faulty or questionable readings from depth sounders may be caused by noise from vertical walls and structures or from silty bottoms containing "fluff” or light suspended material. Manual collection methods can be used to confirm "fluff” type conditions and possibly determine the type of material on reservoir and river bottoms.

Acoustic depth sounding equipment is preferred because it provides a continuous record and chart of the bottom profile. The basic components are the recorder, transmitting and receiving transducer, and power supply. The echo sounders are usually portable recorders that measure the time required for a sound wave to travel from its point of origin to the bottom and back to the origin. The time interval is converted to distance (depth) below the face of the sending plate or transducer. The transmission of sound is dependent on the properties of the water and reflecting surface and assumes a constant velocity throughout the depth measured. Since constant velocity is not the case, sounders usually are designed to permit adjustments (calibration) for the variations in the sound velocity in the water. Calibrations of the echo sounder are critical in assuring high-quality depth measurements. The largest and most critical correction results from the variability of the sound velocity in water due to temperature changes, but other factors such as water density, salinity, turbidity, and depth also affect sound velocity. For most single beam, shallow water, echo sounding work, an average velocity of sound is usually assumed. A bar check calibration determines the actual depth at the study area, and the sounder is adjusted to measure the correct depth. A bar check consists of lowering an acoustic reflector, such as a flat metal plate or I-beam, to a known depth (below the transducer) and manually adjusting the sound velocity to produce an equivalent depth reading.

More or less advanced and complex systems based on the sounding principle exist. The two main groups relevant to reservoir surveys are:

- single beam echo sounder
- multi-beam echo sounder

The multi-beam type sounder offers great detail and has the potential to provide very high accuracy. But being far more complex and time consuming to handle during the survey but particularly in the calibration and data processing, it is recommended that a single beam system is used for reservoir surveys in EN countries.

The following information will therefore deal with single beam systems. When setting up and using any system, the manufacturer specifications and manuals should be consulted. Interpreting depth records takes experience. The most reliable interpretation usually comes from the survey collection crew or someone who has survey collection experience. During interpretation, a plot of the digital record and bottom charts should be studied. In general, if any recorded traces on the graphic or digital record cannot be attributed with reasonable certainty to reflections from the reservoir bottom, the traces should not be part of the final recorded files. The echo sounder's trace on hard bottoms will reflect more strongly than on soft bottoms and will appear as a thin, dark trace on analogue charts. In shallow conditions, multiple echoes may appear with the actual depth being the shallowest reading of the trace. Soft bottoms of unconsolidated materials may produce a broad trace, and sometimes the thickness of the fluff or soft layer can be determined by a split in the echo trace on the analogue chart. These types of conditions usually need to be resolved in the field to confirm the true bottom versus the digital reading. This may be done by using the lead-line or sounding-cable method. Interpretations of the analogue and digital depth data are sometimes made very difficult by the presence of heavy vegetation, floating objects, bottom projections and depressions representing sudden bottom changes, and steep bottom slopes.

5. Survey accuracy

The accuracy of a bathymetric survey is difficult to monitor relative to conventional land-based surveys, due to the lack of available control checks. Care must be taken in instrument calibration and collection procedures to ensure quality data collection, since adjusting the data during post-processing is very difficult. Calibrations and verifications of the collection systems take some time, but are necessary procedures to ensure the quality of the data. The accuracy of the measured bottom is dependent on the many inherent errors in the measuring process, and it is up to the collection crew to minimize these errors. Using experienced collection crews that utilize good collection techniques is one of the best means of ensuring proper survey methods, usually resulting in accurate survey data. The horizontal position of a bathymetric survey is usually established by an open-end survey method with no independent check, so the accuracy is totally dependent on the measuring process. The vertical measurement reference is usually the variable water surface and is independent of the horizontal measurement, except for the time of collection relationship, which allows the hydrographic survey software to merge each depth measurement (elevation) with its corresponding position (horizontal coordinates). The accuracy of the bathymetric survey is dependent on the accuracy of each instrument, calibration, correlation of all system components, collection method and techniques, corrections to the collected data, equipment selection and maintenance and analysis techniques.

An important distinction exists between the accuracy and precision of the bathymetric survey. The estimated accuracy of a survey is usually based on results from the equipment calibration. Other techniques to determine the accuracy of the bathymetric survey include cross-checking lines and repeat surveys. Computer software packages have routines to compute position accuracy for the automated bathymetric survey instruments that give the survey crew the option of making adjustments to minimize collection errors. Statistical software package allows the collection crew to compute and display differences between intersecting survey lines. Such programmes will also provide a statistical report that shows the standard deviation distribution and average error. The output report contains detailed information for every intersecting point along with a three-dimensional view of the intersecting survey lines displaying the depth differences.

An additional potential error with the automated bathymetric survey systems is the synchronization of the recorded data by the collection software (latency time). Latency is the time delay from the instant a measurement is taken by a survey instrument to the instant the instrument outputs the measurement data to the survey computer software. The position error will usually increase with increased velocity of the survey boat, and some systems have a time delay as long as 2 seconds. Current software has several methods of determining the time lag and correcting for it. Cross section plots illustrate the shift in the horizontal positions if a time lag exists. The adjustments can be made during the analysis process, but it is best to determine the lag time prior to data collection.

6. Survey personnel

Personnel requirements vary by the size of the job, type of equipment, and method of collection. Qualified and experienced personnel are essential for an efficient and productive field operation, with a key being a chief surveyor experienced in all phases of the field operations and knowledgeable about the computation and report needs of the survey. The crew members must be capable of assisting in the operation and maintenance of the field instruments. Current systems allow data collection by as few as one person but, for safety purposes and assistance, a minimum of two field personnel is recommended for bathymetric survey vessel operations. For larger reservoirs, one or two additional crewmembers may be necessary for support of the survey, safety of the operation, operation of an auxiliary boat, transporting fuel and supplies to the survey boat, and setting up and maintaining any necessary shore-based equipment. Personnel should be trained in first-aid, cardiopulmonary resuscitation (CPR), and survey vessel operation.

Once this operation is set up and running, with a number of survey teams in operation, it should be considered to establish a certification program for hydrographic/bathymetric surveyors.

7. Determination of deposited volume

Upon completion of the field surveys, the accumulated data must be assembled and analyzed for the purpose of calculating an updated elevation versus storage volume relationship for the reservoir. Comparing the new storage volume results with the original or previous baseline survey results can determine the volume of the accumulated sediment. It is recommended that all resulting long-term total sediment computations be compared to the original capacity.

Ideally, identical computational methods should be used for each survey. For some reservoirs, advances in technology have made this difficult or impossible because the accuracy of the resurveys is better than the original collected data. In some cases, the accuracy difference is very pronounced.

The contour method, which creates a new reservoir topographic map, has become the preferred method for collecting and analyzing survey data. The development of electronic measuring and computerized collection and analysis systems has made it possible for collection and analysis of massive amounts of digital data (x, y, z coordinates), and the final product yields an accurate detailed contour map of the present reservoir conditions.

The contour method involves determining current water volumes and sediment deposition from newly developed reservoir topographic contours, allowing a three-dimensional view on a two-dimensional medium. The final results from the reservoir contour maps are generated surface contours at selected elevation intervals that are used to compute updated volumes. There are multiple computer contour packages and routines for personal or work station computer systems that can be used for this purpose.

There are several computer programs that can generate elevation versus surface area and capacity for a reservoir. Total volume of sediment deposited in the reservoir generally may be determined as the difference between the original reservoir capacity and the updated capacity computed from the resurvey. Both capacity computations should be made by the same method. Even though all volume computation methods are basically similar, this eliminates any variation in calculations resulting from differences between computational procedures.

In reservoirs where significant compaction of sediment occurs between subsequent surveys, the difference in reservoir storage would not be truly representative of sediment deposition in the intervening time periods. For those reservoirs, the rate of sediment accumulation should be computed for the total storage period, based on the difference in capacity between the original and present capacity. The results should note the compaction. Ideally, bottom sampling should be part of these studies to provide density measurements for each survey. Extreme caution must be taken in comparing survey results when it comes to vertical datums. The use of GPS allows accurate horizontal and vertical control to be established.

The use of the contour method includes the capacity changes due to bank erosion and is the preferred method for a resurvey. If sediment inflow and outflow records are obtained for the period between surveys, these are useful in the analysis of the sedimentation characteristics of the reservoir.

The trap efficiency of the reservoir may be determined when sediment inflow and outflow records are available for the period between surveys, but such data will usually not be available and their collection is time consuming and associated with high accuracy problems. When the records are available, the trap efficiency for the period between surveys should be computed and compared with predictive methods.

8. Survey report

An important feature of any reservoir survey is the report of results, so that others may benefit from the time and effort expended in the investigation. The information gathered during a detailed survey helps define the sedimentation characteristics of the contributing drainage basin as well as the reservoir. A well-prepared report that follows a set standard is essential. The format of the report should be thought out carefully before the first surveys and subsequently further developed taking into account the experience from accomplished surveys.

The report should be as inclusive as necessary to document the survey and provide the information useful for future surveys as well as for analyses and interpretations. The items included in individual reports may vary according to the problems and circumstances encountered. Some of the important items that may be included in a report are:

- General information on the dam, reservoir, and drainage basin.
- Information on all surveys, past and present, conducted on the reservoir.
- Description of the survey and sampling techniques for the present survey and the special equipment used.
- A reservoir map showing the survey track lines
- A plot showing the areas surveyed
- The newly developed contour map of the reservoir
- A description of all major survey controls with a table listing horizontal and vertical Information, including control datum used
- A plot or table showing the reservoir stage fluctuation
- Profiles of all reservoir and degradation ranges showing the latest survey superimposed on the original profile and, in some cases, plots from other surveys.

- Graphs of sediment distribution in a longitudinal profile, a percent depth versus percent sediment volume, and a percent depth versus percent distance from the dam plot
- Data in tabular and graphic form describing sediment densities and particle sizes (if included)
- Revised area and capacity tables and curves resulting from the new survey
- Any data on sediment inflow and outflow that may be available for estimating trap efficiency

9. Bathymetric surveys for large reservoirs

For large reservoirs such as the Lake Nasser/Nubia it may be considered to use more advanced techniques, ref. SWECO (2007). In the programming study done by SWECO a Monitoring System Implementation Study for Lake Nasser/Nubia was described. The Monitoring System would integrate monitoring in its usual sense, but also remote sensing analyses, mathematical modelling and establishing of databases.

For the bathymetric surveys the following is specified:

The bathymetric survey techniques shall be upgraded to make the surveys more cost effective in the long run and delivering results to satisfy any future requirements. The project will upgrade the survey techniques to state-of-the-art methods that are the most suited for Lake Nasser/Nubia. This will be done through surveys carried out during project execution. Following the evaluation of the outcome, changes shall be made to obtain the best combination of techniques.

- The techniques to be tested and implemented if they are found suitable are:
- multibeam echo sounder for bathymetric surveys
- LIDAR green and red light bathymetry/topography methods for bathymetry (in areas of clear water, eg at low inflow/shallow water)
- bed penetrating sonar, to test the possibility of detecting annual layering

Based on the findings from the surveys carried out in the course of the project, the best suited instruments and auxiliary equipment and software will be acquired. Staff will be trained in the use of the equipment, as well as in the handling and analysis of data using the analysis software.

The advantage of using LIDAR green light for bathymetry of shallow areas compared with multi-beam surveys over water is illustrated in Figure A3-1 below. It is evident that the multi-beam echo-sounder is less efficient on shallow water. Therefore, a near-shore LIDAR survey can take over near the shore and even on the shores up to maximum water level.

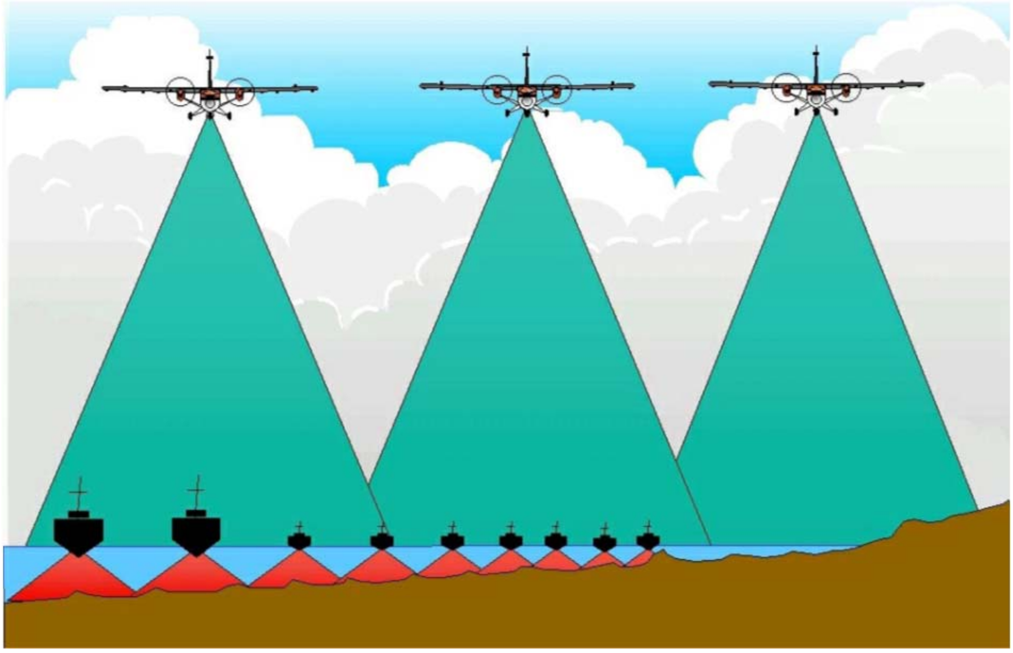


Figure A3-1 Principles of LIDAR survey and multi-beam echo-sounder survey in shallow areas (from SWECO, 2007)

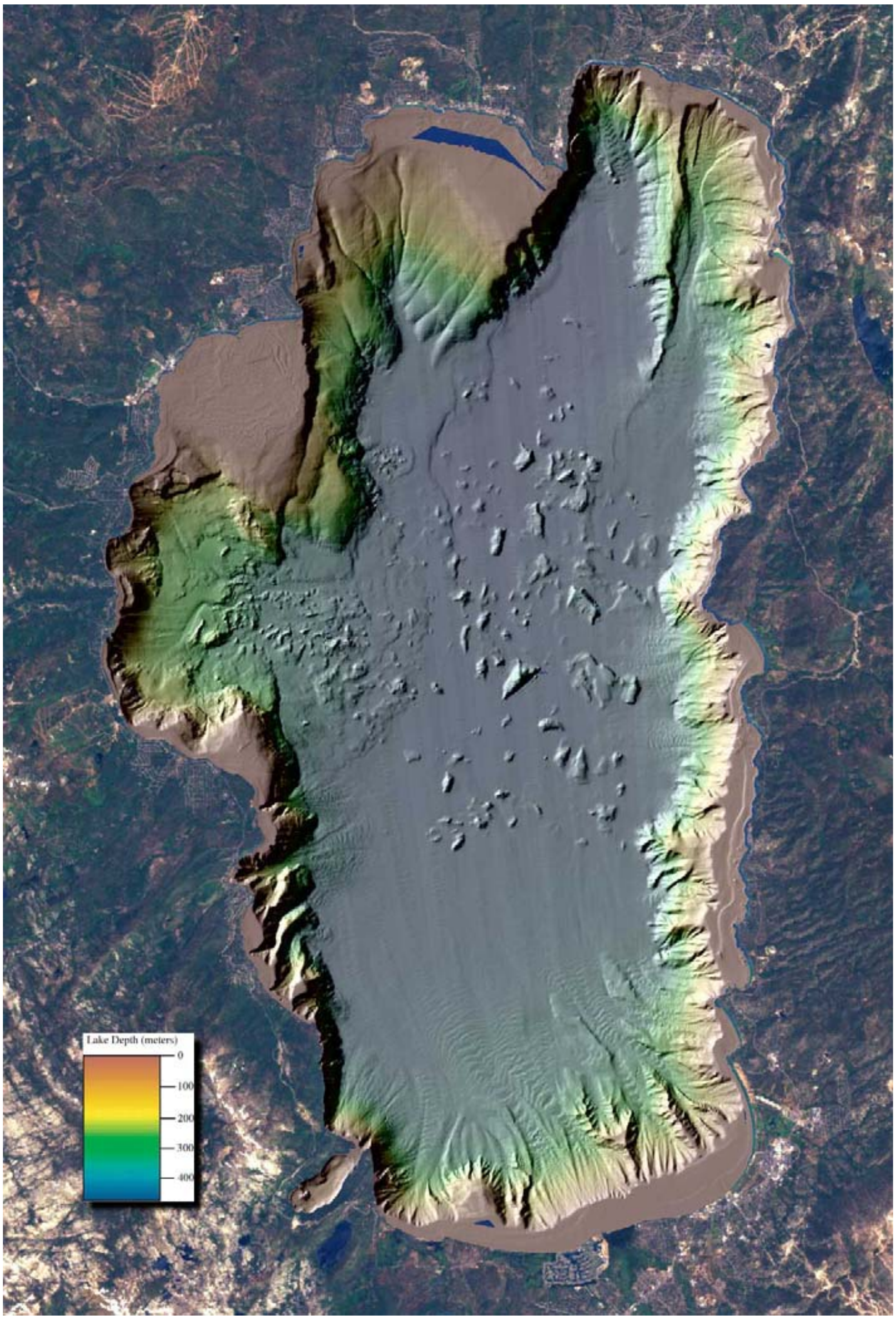


Figure A3-2 Combined LIDAR (to 15m depth) and multi-beam echosounder (from 10m depth and to bottom) survey of Lake Tahoe http://walrus.wr.usgs.gov/pacmaps/lt-shoal.html (from SWECO, 2007)

Should, for some reason, LIDAR surveys not be suitable, an alternative method of obtaining the levels between minimum and maximum Lake water levels may be used. This method uses satellite images taken at a variety of different water levels. As the water level is known, it will be possible draw the shoreline for each case, and thereby finally obtain the Lake bed topography between low and high water level.

The grain size distribution of bed sediments is related to the prevailing flow conditions at the time of settlement. Coarser fractions will settle during relatively high turbulence and thereby high flow velocities, while the finer fractions will settle only in relatively calm water.

Grain size distribution can be determined from samples taken of the top layer (by for instance van Veen grab sample method) or from deeper layer by drilling and core sampling.

While the sampling of bed sediment is simple and inexpensive, the core sampling requires more effort to ensure samples represent the depth where they are taken, in order to establish the stratigraphic series of layers, for instance with an annual sequence. Setting up a drilling rig on the soft unconsolidated bed may cause problems due to penetration of the legs into the bed. Other methods involve lowering an underwater facility for bed penetration and sampling. While penetrometer testing may be sufficient to register a layering with say an annual sequence, sampling would be required to determine sediment quality data.

The determination of sediment quality properties may be useful, mainly in deciding on the potential use of the sediment, but also to investigate the possible content of pollutants. Determining the consolidation characteristics of deposited sediment is required to calculate the sediment balance of the Lake and to predict the future consolidation. Possible improved techniques to be tested will include:

- acoustic sub-bottom profiler (single or multi beam)
- submerged penetrometer
- sub-surface sampling techniques

In addition to these may come laboratory techniques tailored to determining the characteristics of the sediment as required.

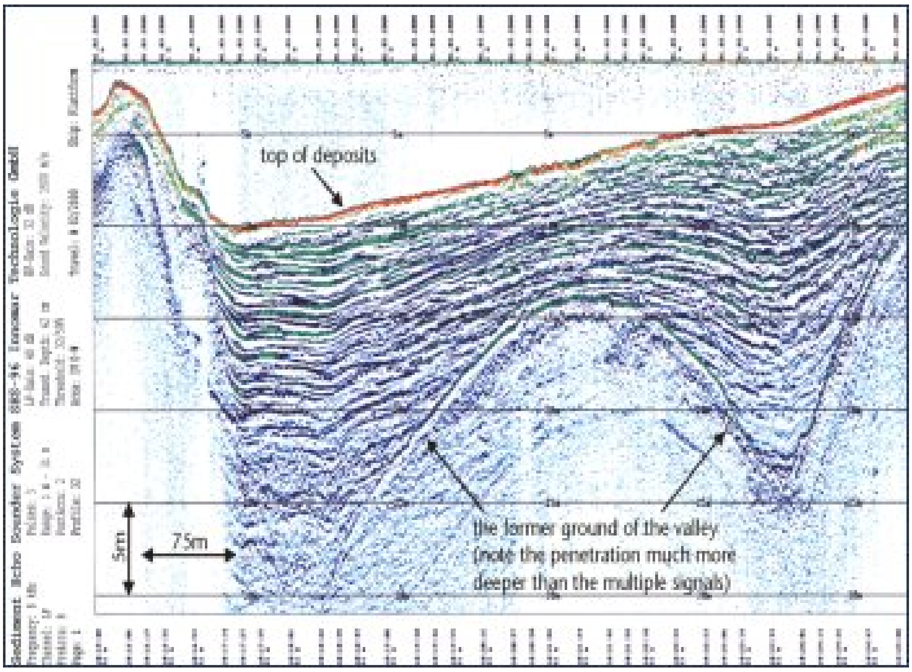


Figure A3-3 Echo print example from a German lake filled with deposits (INNOMAR SES 2000 Light from RESON) (from SWECO, 2007).

Annex 3: Maps for planning of Monitoring Network

The following are comments on the maps shown in the Annex.

Monitoring stations & River Networks of Abbay River Basin

The map shows the river network and the monitoring stations along with the existing road network. It is very obvious that stations have been placed where there is road access. New roads with construction or design in progress are not shown. A few stations fall outside the river network due to inaccuracy in coordinates.

Monitoring stations Roads & Sub-catchments of Abbay River Basin

The map shows the river network and the monitoring stations along with new roads with construction or design in progress. The existing road network is not shown. Also subcatchments is shown, to visualise how the subcatchment coverage is and where stations are placed in the subcatchments.

Monitoring stations & Sheet Erosion of Abbay River Basin

The map shows the river network and the monitoring stations along with the existing road network. More importantly it shows the areas that have calculated high sheet erosion. From this it can be checked if sediment gauging stations are placed to pick up sediment transport originating from these areas. Areas of other types of erosion should be checked in similar way.

Monitoring stations & Roads Under Con. Tekeze River Basin

The map shows the river network and the monitoring station along with new roads with construction or design in progress. The existing road network is not shown. Also subcatchments is shown, to visualise how the subcatchment coverage is and where stations are placed in the subcatchments.

Monitoring stations & Annual Rainfall of Tekeze River Basin

The map shows the river network and the monitoring stations. The road network is not shown. Also the rainfall map of the catchment is shown. This makes it possible to check if areas with high rainfall are well represented in the monitoring network.

Monitoring Stations & Roads Under Construction Baro- Akobo River Basin

The map shows the river network and the monitoring stations along with new roads with construction or design in progress. The existing road network is not shown.

Monitoring Stations & Sub-catchment of Baro - Akobo River Basin

The map shows the river network and the monitoring stations. The existing road network is not shown. Also subcatchments is shown, to visualise how the subcatchment coverage is and where stations are placed in the subcatchments.
Monitoring Stations & Rainfall of Baro - Akobo River Basin

The map shows the river network and the monitoring stations. The road network is not shown. Also the rainfall map of the catchment is shown. This makes it possible to check if areas with high rainfall are well represented in the monitoring network.

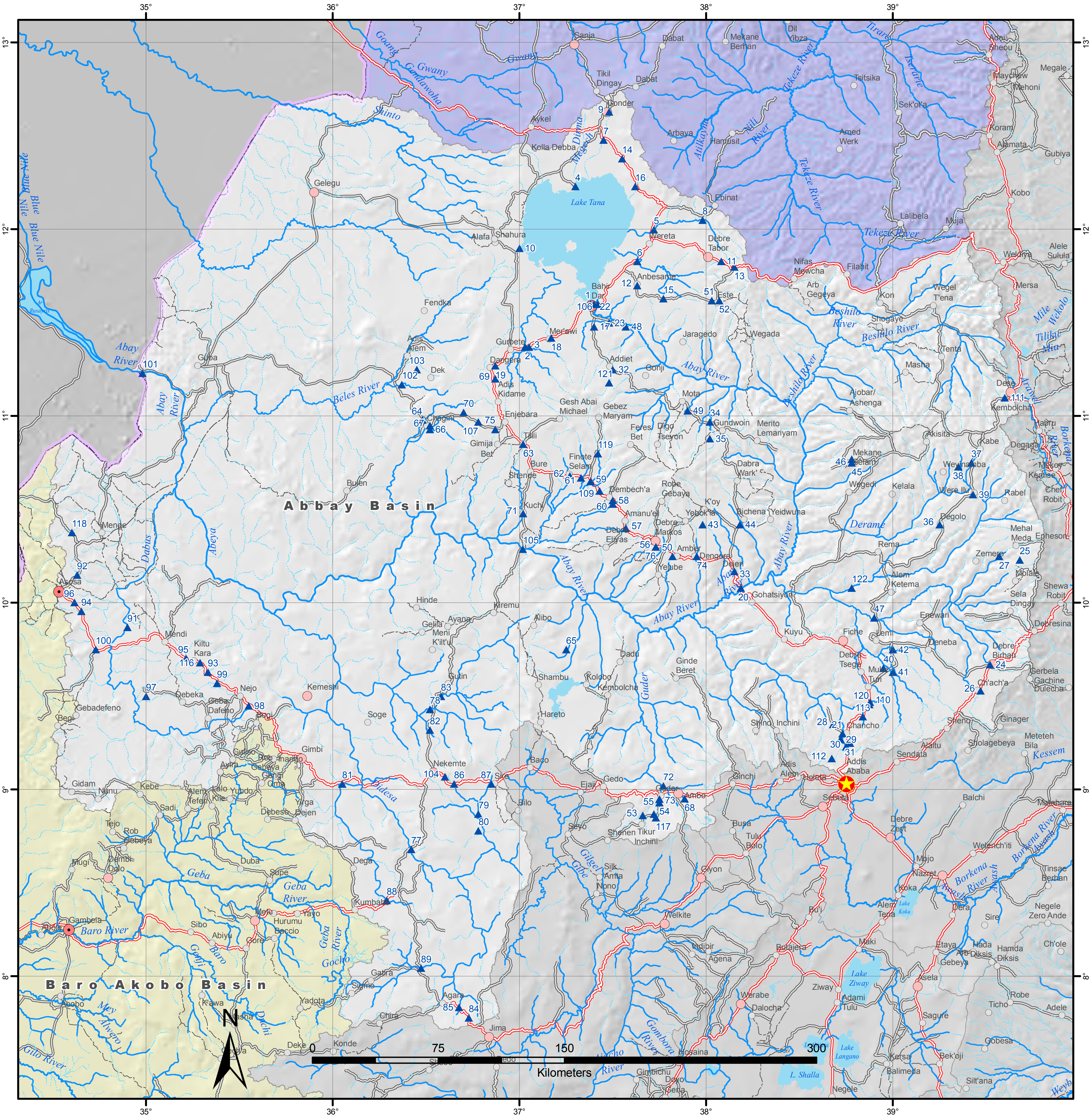
Monitoring Stations & Sheet Erosion in Baro - Akobo River Basin

The map shows the river network and the monitoring. It also shows the areas that have calculated high sheet erosion. From this it can be checked if sediment gauging stations are placed to pick up sediment transport originating from these areas. Areas of other types of erosion should be checked in similar way.

Ethiopia: Road Networks & River Basins

The maps show the river network and the road network. Important here is that gravel and sand/dirt roads are also shown. These may be needed to reach some potential station locations.

Monitoring stations & River Networks of Abbay River Basin



Legend

- ▲ Monitoring stations
- ★ Capital City
- ● Regional Capital
- ● Zonal Capital
- ● Wereda Capital
- Paved
- Gravel
- Dirt/Sand

Rivers

- Major Rivers
- Secondary Rivers
- Streams
- Lake
- International boundary

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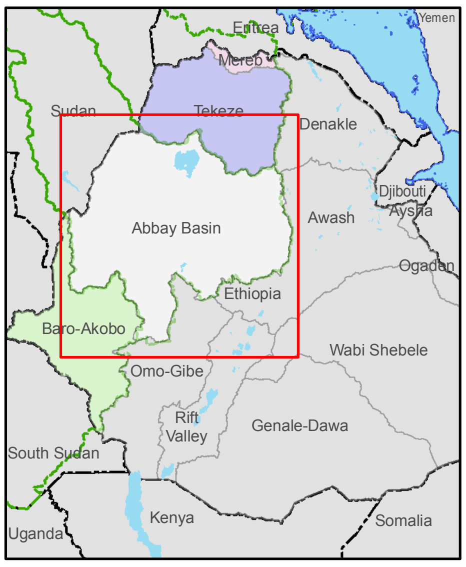
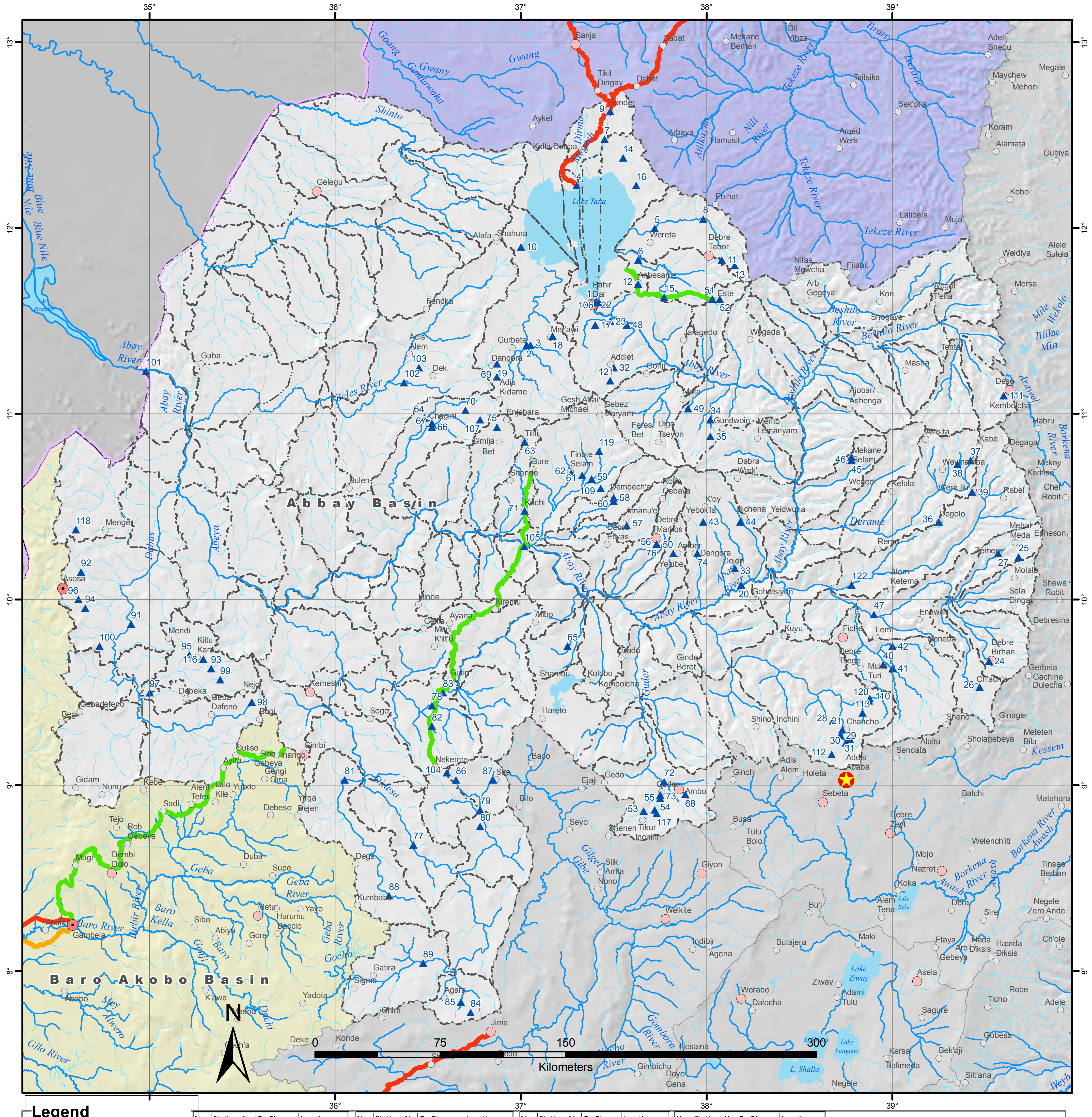


January 2012, Addis Ababa, Ethiopia.

Monitoring stations Roads & Sub-catchments of Abbay River Basin



Legend

▲ Monitoring stations
★ Capital City
● Regional Capital
○ Zonal Capital
○ Wereda Capital

Roads Under Construction
On-going
On-going gravel
Design level

Rivers
Major Rivers
Secondary Rivers
Streams
sub-catchments
Lake
International boundary

No_	Station_No	On River	Location
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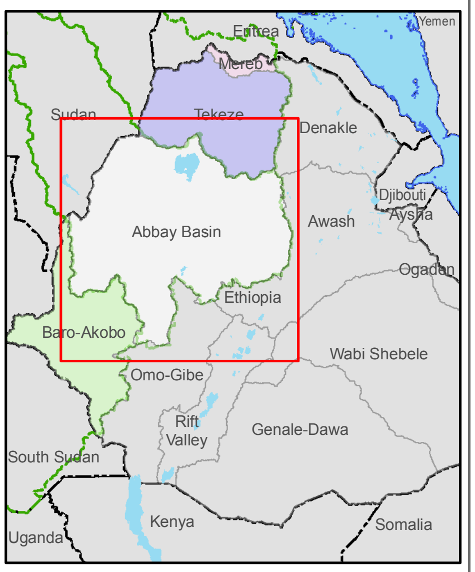
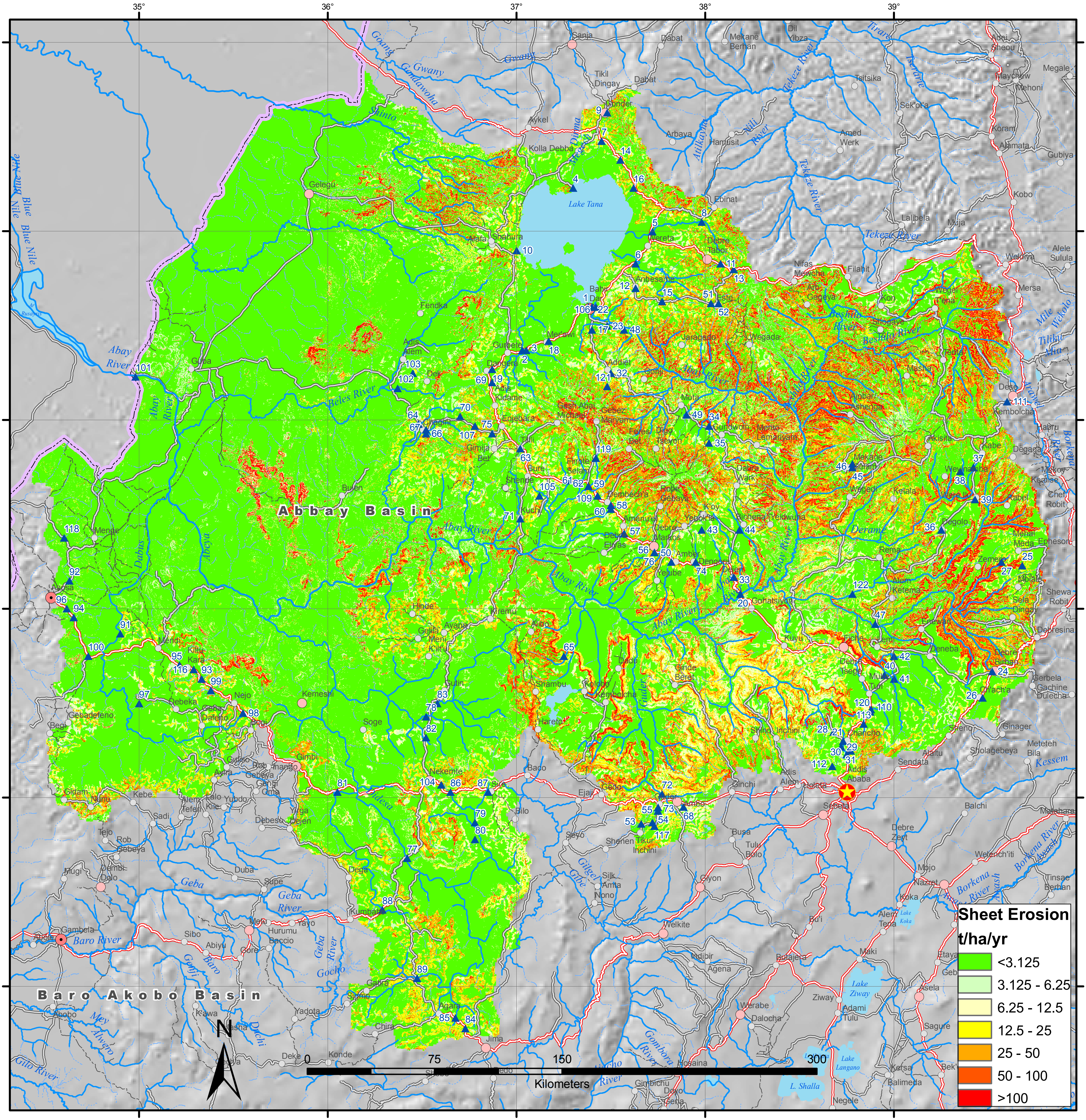


January 2012, Addis Ababa, Ethiopia.

Monitoring stations & Sheet Erosion of Abbay River Basin



Legend

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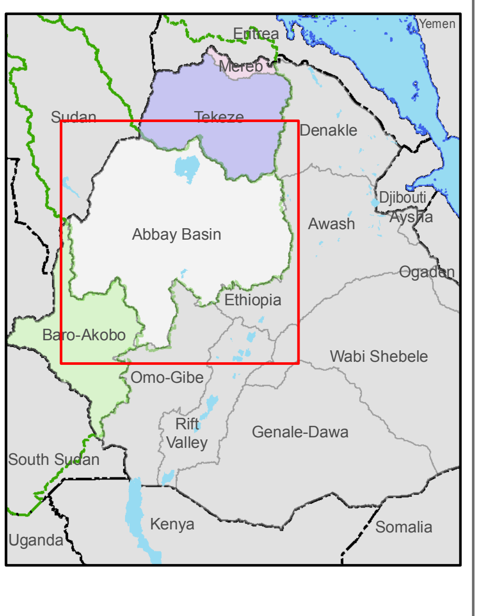
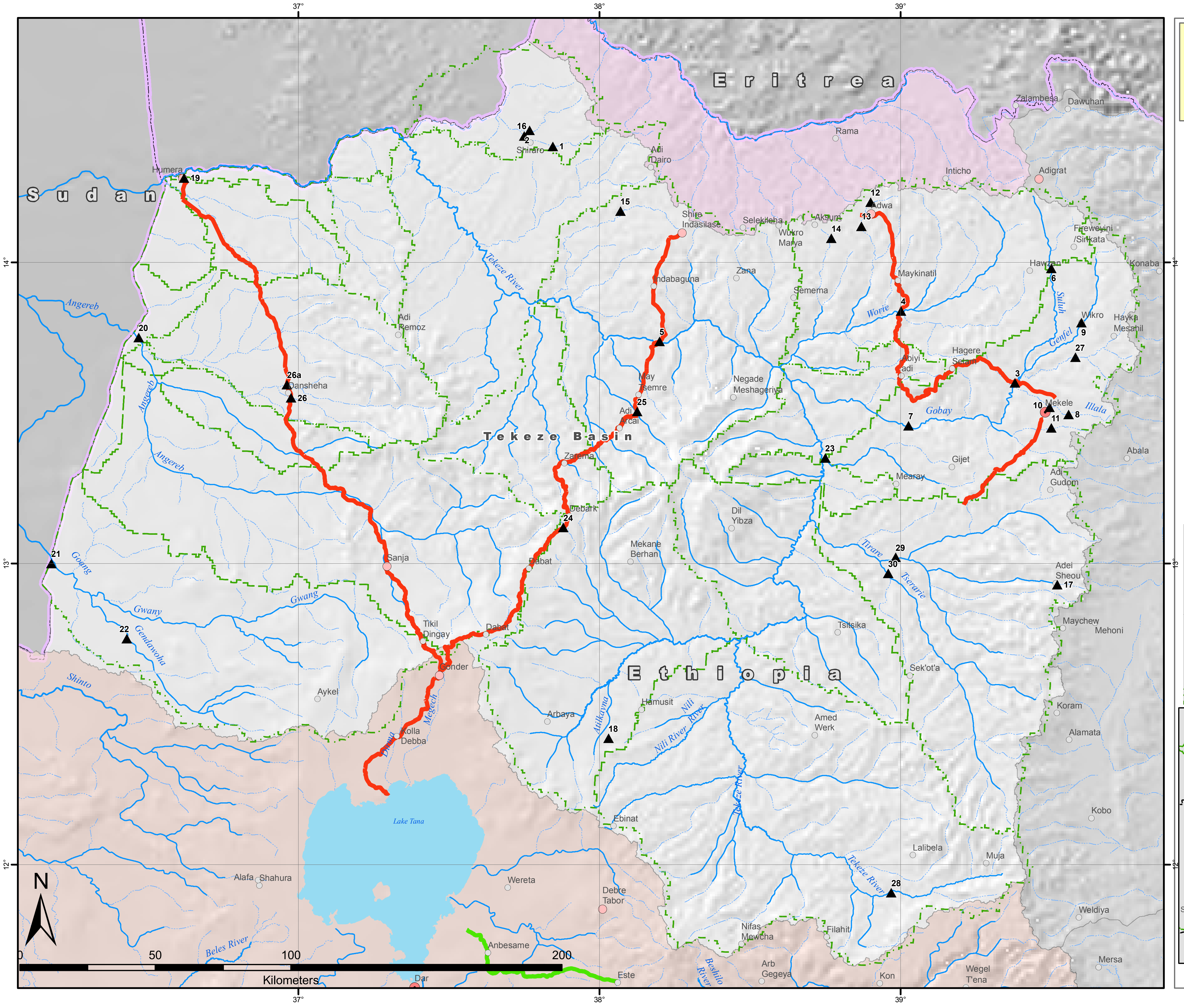


January 2012, Addis Ababa, Ethiopia.

Monitoring stations & Roads Under Con. Tekeze River Basin



NO	Staion_No	On River	Location
1		INDAASA	Nr. RAMA
2	121019	MEHAQUAN	Nr. RAMA
3	121004	GHEBA	Nr. MEKEL
4	121005	WORIE	Nr. MAIKE
5	121006	TEKEZE	Nr. EMBAM
6	121007	SULLUH	Nr. HAWSI
7	121008	GHEBA	Nr. ADI K
8	121009	DOLO	NR. QUIHA
9	121010	GENFEL	@ WUKRO
10	121011	ILLALA	Nr. MEKEL
11	121012	METERE	Nr. AINAL
12	121014	MAY DUNGU	Nr. ADWA
13	121015	MAY MIDIM	Nr. ADWA
14	121017	AYEHIDA	Nr. AXUM
15	121018	SEBTTA	Nr. ADIDA
16	121019	MOLGE	Nr. SHIRA
17	121020	ATSELA	Nr. ADISH
18	122001	ZAREMA	@ ZAREMA
19	122002	TEKEZE	@ HUMERA
20	123001	ANGAREB	Nr. ABDI
21	124001	GOANG	Nr. METEM
22	124002	GENDAWOHA	Nr. KOKIT
23		TEKEZE	Nr. YECHI
24		ASERA	Nr. DEBAR
25		BUYA	Nr. MAITS
26		MEKEZO	Nr. DANSH
27	121013	AGULA	NR. AGULA
28		TEKEZE	NrKULMESK
29		ZAREMA	Nr. YECHI
30		TSERARIE	Nr. SEKOT
26a		MEKEZO	Nr. DANSH

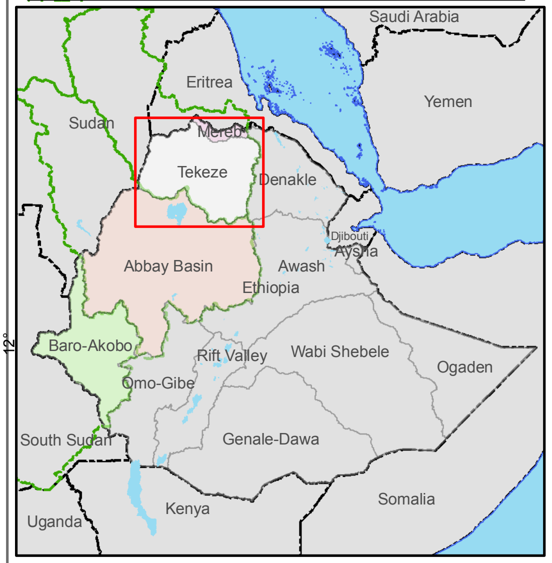
Legend

Towns
- Regional Capital
- Zonal Capital
- Wereda Capital

Roads Under Con.
- On-going
- Design level
- Sub-Catchment

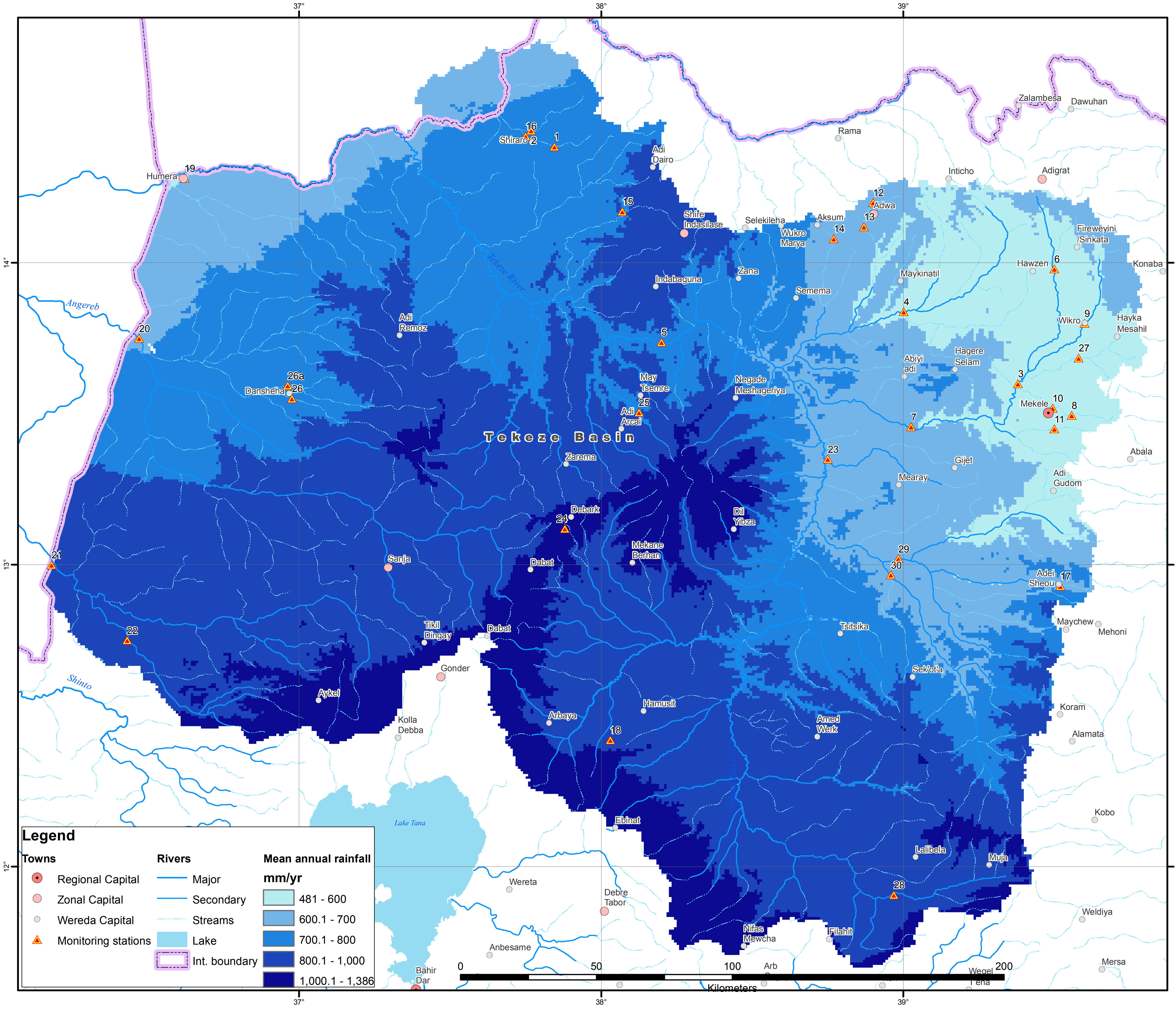
▲ Monitoring stn.

Rivers
- Major
- Secondary
- Streams
- Lake
- Int. boundary



January 2012, Addis Ababa Ethiopia.

Monitoring stations & Annual Rainfall of Tekeze River Basin



NO	Staion_No	On River	Location
1		INDAASA	Nr. RAMA
2	121019	MEHAQUAN	Nr. RAMA
3	121004	GHEBA	Nr. MEKEL
4	121005	WORIE	Nr. MAIKE
5	121006	TEKEZE	Nr. EMBAM
6	121007	SULLUH	Nr. HAWSI
7	121008	GHEBA	Nr. ADI K
8	121009	DOLO	NR. QUIHA
9	121010	GENFEL	@ WUKRO
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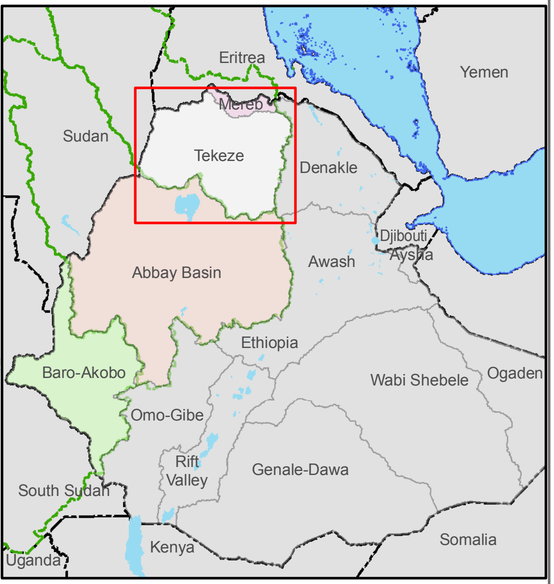
12	121014	MAY DUNGU	Nr. ADWA
13	121015	MAY MIDIM	Nr. ADWA
14	121017	AYEHIDA	Nr. AXUM
15	121018	SEBTTA	Nr. ADIDA
16	121019	MOLGE	Nr. SHIRA
17	121020	ATSELA	Nr. ADISH
18	122001	ZAREMA	@ ZAREMA
19	122002	TEKEZE	@ HUMERA
20	123001	ANGAREB	Nr. ABDI
21	124001	GOANG	Nr. METEM
22	124002	GENDAWOHA	Nr. KOKIT
23		TEKEZE	Nr. YECHI
24		ASERA	Nr. DEBAR
25		BUYA	Nr. MAITS
26		MEKEZO	Nr. DANSH
27	121013	AGULA	NR. AGULA
28		TEKEZE	NrKULMESK
29		ZAREMA	Nr. YECHI
30		TSERARIE	Nr. SEKOT
26a		MEKEZO	Nr. DANSH

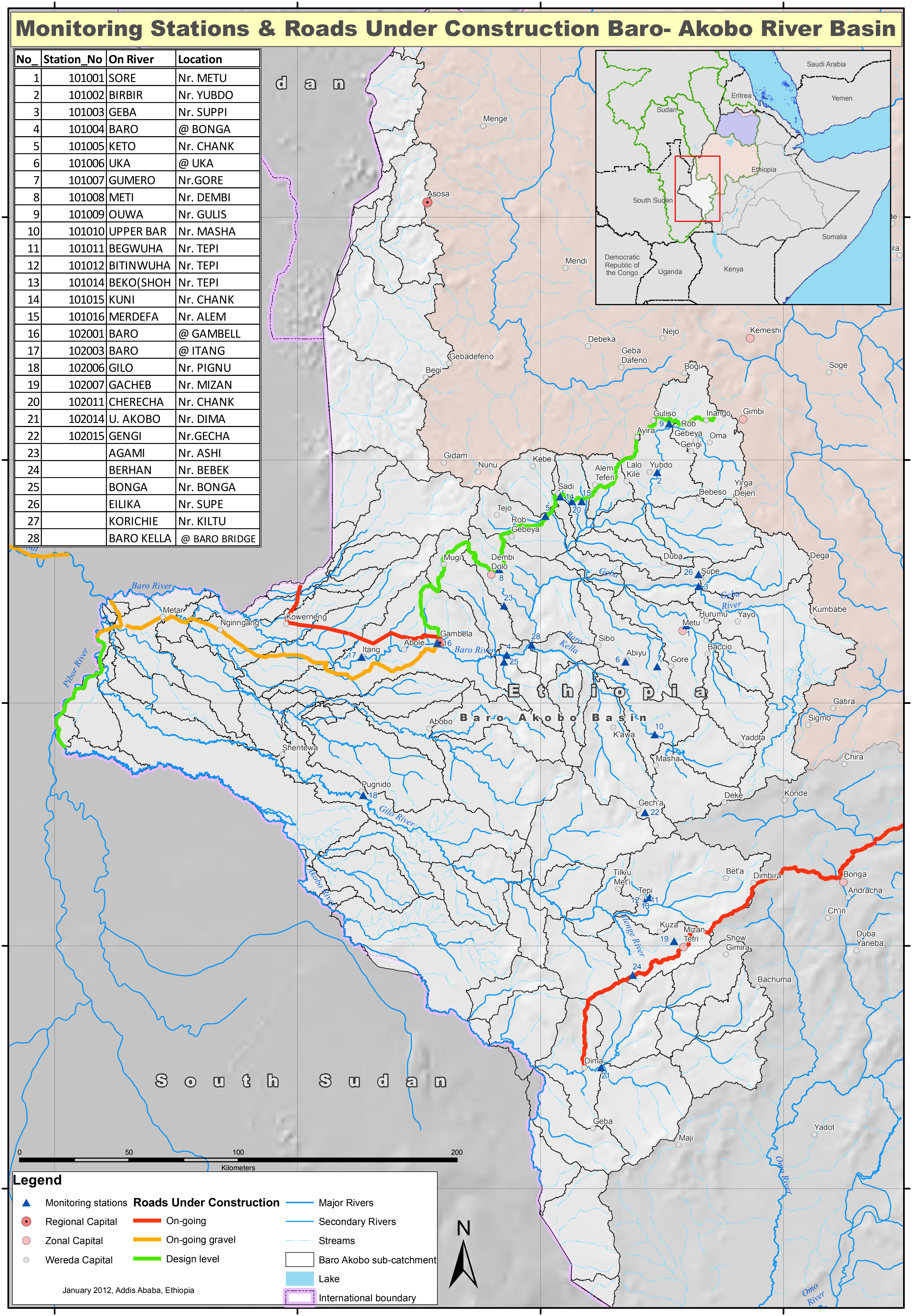
N



January 2012, Addis Ababa Ethiopia.

Monitoring Stations & Roads Under Construction Baro- Akobo River Basin

No_	Station_No	On River	Location
1	101001	SORE	Nr. METU
2	101002	BIRBIR	Nr. YUBDO
3	101003	GEBA	Nr. SUPPI
4	101004	BARO	@ BONGA
5	101005	KETO	Nr. CHANK
6	101006	UKA	@ UKA
7	101007	GUMERO	Nr.GORE
8	101008	METI	Nr. DEMBI
9	101009	OUWA	Nr. GULIS
10	101010	UPPER BAR	Nr. MASHA
11	101011	BEGWUHA	Nr. TEPI
12	101012	BITINWUHA	Nr. TEPI
13	101014	BEKO(SHOH	Nr. TEPI
14	101015	KUNI	Nr. CHANK
15	101016	MERDEFA	Nr. ALEM
16	102001	BARO	@ GAMBELL
17	102003	BARO	@ ITANG
18	102006	GILO	Nr. PIGNU
19	102007	GACHEB	Nr. MIZAN
20	102011	CHERECHA	Nr. CHANK
21	102014	U. AKOBO	Nr. DIMA
22	102015	GENGI	Nr.GECHA
23		AGAMI	Nr. ASHI
24		BERHAN	Nr. BEBEK
25		BONGA	Nr. BONGA
26		EILIKA	Nr. SUPE
27		KORICHIE	Nr. KILTU
28		BARO KELLA	@ BARO BRIDGE



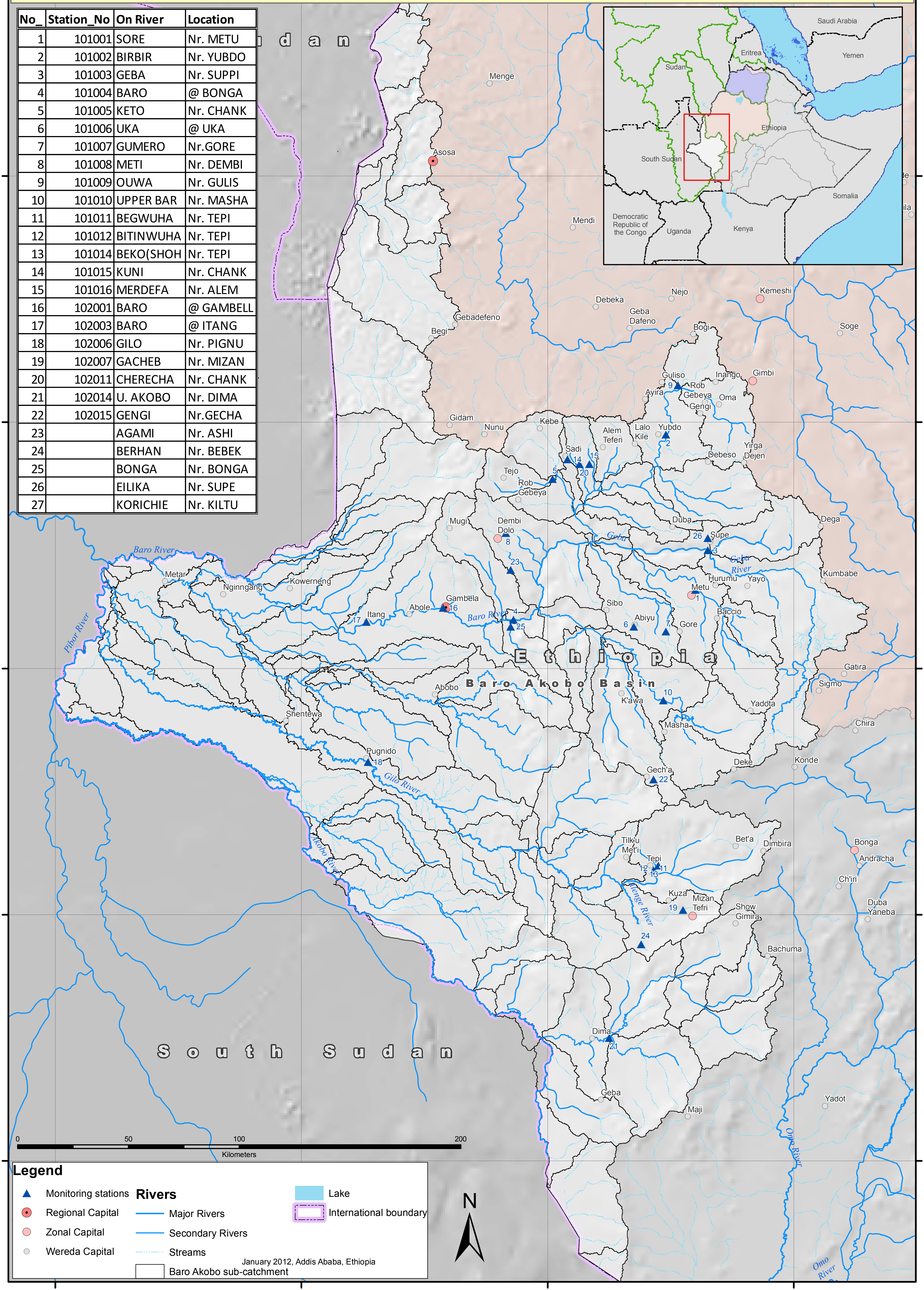
Legend

▲ Monitoring stations	**Roads Under Construction**	Major Rivers
● Regional Capital	On-going	Secondary Rivers
● Zonal Capital	On-going gravel	Streams
● Wereda Capital	Design level	☐ Baro Akobo sub-catchment
		Lake
		International boundary

January 2012, Addis Ababa, Ethiopia

Monitoring Stations & Sub-catchment of Baro - Akobo River Basin

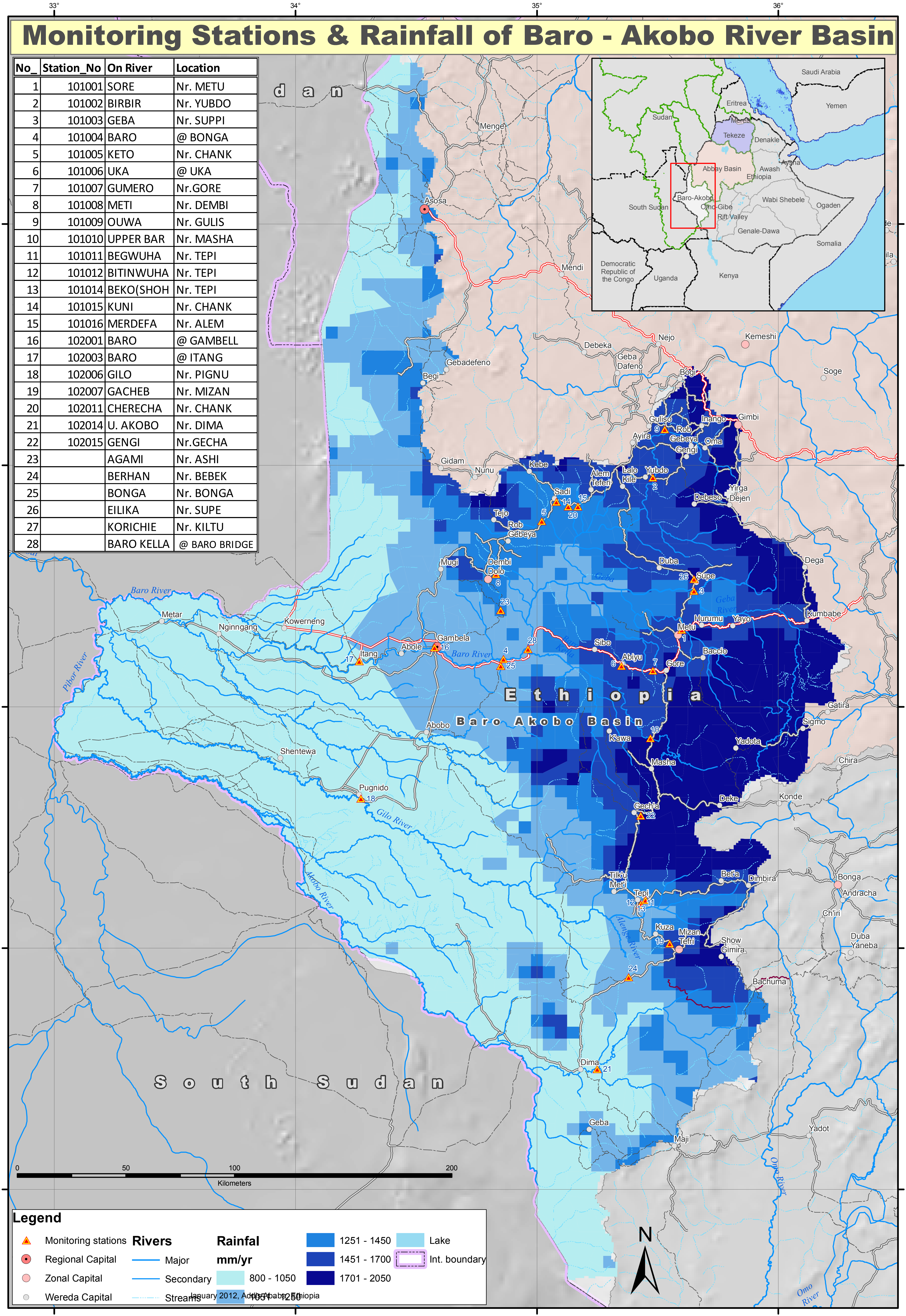
No_	Station_No	On River	Location
1	101001	SORE	Nr. METU
2	101002	BIRBIR	Nr. YUBDO
3	101003	GEBA	Nr. SUPPI
4	101004	BARO	@ BONGA
5	101005	KETO	Nr. CHANK
6	101006	UKA	@ UKA
7	101007	GUMERO	Nr.GORE
8	101008	METI	Nr. DEMBI
9	101009	OUWA	Nr. GULIS
10	101010	UPPER BAR	Nr. MASHA
11	101011	BEGWUHA	Nr. TEPI
12	101012	BITINWUHA	Nr. TEPI
13	101014	BEKO(SHOH	Nr. TEPI
14	101015	KUNI	Nr. CHANK
15	101016	MERDEFA	Nr. ALEM
16	102001	BARO	@ GAMBELL
17	102003	BARO	@ ITANG
18	102006	GILO	Nr. PIGNU
19	102007	GACHEB	Nr. MIZAN
20	102011	CHERECHA	Nr. CHANK
21	102014	U. AKOBO	Nr. DIMA
22	102015	GENGI	Nr.GECHA
23		AGAMI	Nr. ASHI
24		BERHAN	Nr. BEBEK
25		BONGA	Nr. BONGA
26		EILIKA	Nr. SUPE
27		KORICHIE	Nr. KILTU



January 2012, Addis Ababa, Ethiopia

Monitoring Stations & Rainfall of Baro - Akobo River Basin

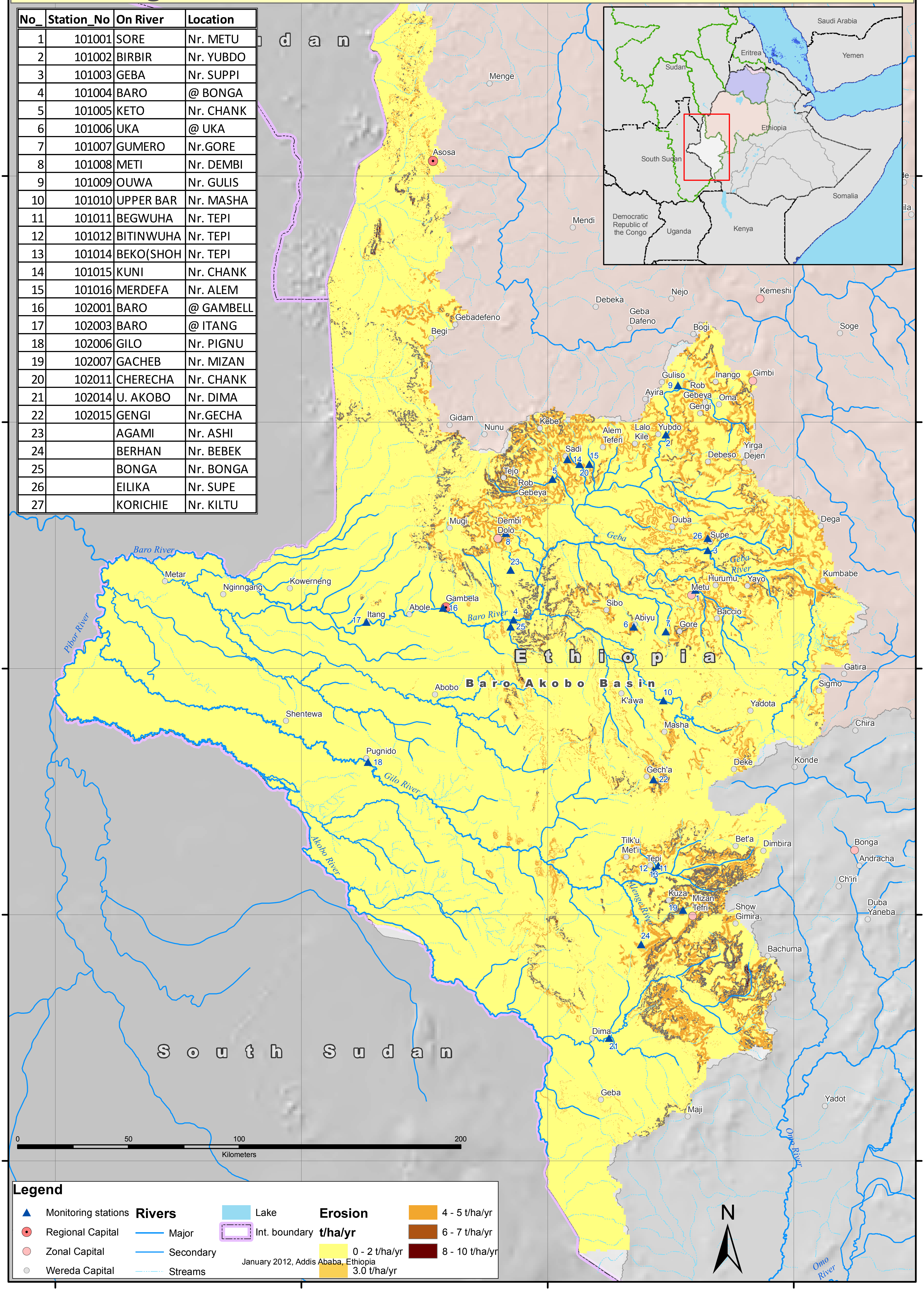
No_	Station_No	On River	Location
1	101001	SORE	Nr. METU
2	101002	BIRBIR	Nr. YUBDO
3	101003	GEBA	Nr. SUPPI
4	101004	BARO	@ BONGA
5	101005	KETO	Nr. CHANK
6	101006	UKA	@ UKA
7	101007	GUMERO	Nr.GORE
8	101008	METI	Nr. DEMBI
9	101009	OUWA	Nr. GULIS
10	101010	UPPER BAR	Nr. MASHA
11	101011	BEGWUHA	Nr. TEPI
12	101012	BITINWUHA	Nr. TEPI
13	101014	BEKO(SHOH	Nr. TEPI
14	101015	KUNI	Nr. CHANK
15	101016	MERDEFA	Nr. ALEM
16	102001	BARO	@ GAMBELL
17	102003	BARO	@ ITANG
18	102006	GILO	Nr. PIGNU
19	102007	GACHEB	Nr. MIZAN
20	102011	CHERECHA	Nr. CHANK
21	102014	U. AKOBO	Nr. DIMA
22	102015	GENGI	Nr.GECHA
23		AGAMI	Nr. ASHI
24		BERHAN	Nr. BEBEK
25		BONGA	Nr. BONGA
26		EILIKA	Nr. SUPE
27		KORICHIE	Nr. KILTU
28		BARO KELLA	@ BARO BRIDGE



January 2012, Addis Ababa, Ethiopia

Monitoring Stations & Sheet Erosion in Baro - Akobo River Basin

No_	Station_No	On River	Location
1	101001	SORE	Nr. METU
2	101002	BIRBIR	Nr. YUBDO
3	101003	GEBA	Nr. SUPPI
4	101004	BARO	@ BONGA
5	101005	KETO	Nr. CHANK
6	101006	UKA	@ UKA
7	101007	GUMERO	Nr.GORE
8	101008	METI	Nr. DEMBI
9	101009	OUWA	Nr. GULIS
10	101010	UPPER BAR	Nr. MASHA
11	101011	BEGWUHA	Nr. TEPI
12	101012	BITINWUHA	Nr. TEPI
13	101014	BEKO(SHOH	Nr. TEPI
14	101015	KUNI	Nr. CHANK
15	101016	MERDEFA	Nr. ALEM
16	102001	BARO	@ GAMBELL
17	102003	BARO	@ ITANG
18	102006	GILO	Nr. PIGNU
19	102007	GACHEB	Nr. MIZAN
20	102011	CHERECHA	Nr. CHANK
21	102014	U. AKOBO	Nr. DIMA
22	102015	GENGI	Nr.GECHA
23		AGAMI	Nr. ASHI
24		BERHAN	Nr. BEBEK
25		BONGA	Nr. BONGA
26		EILIKA	Nr. SUPE
27		KORICHIE	Nr. KILTU



January 2012, Addis Ababa, Ethiopia

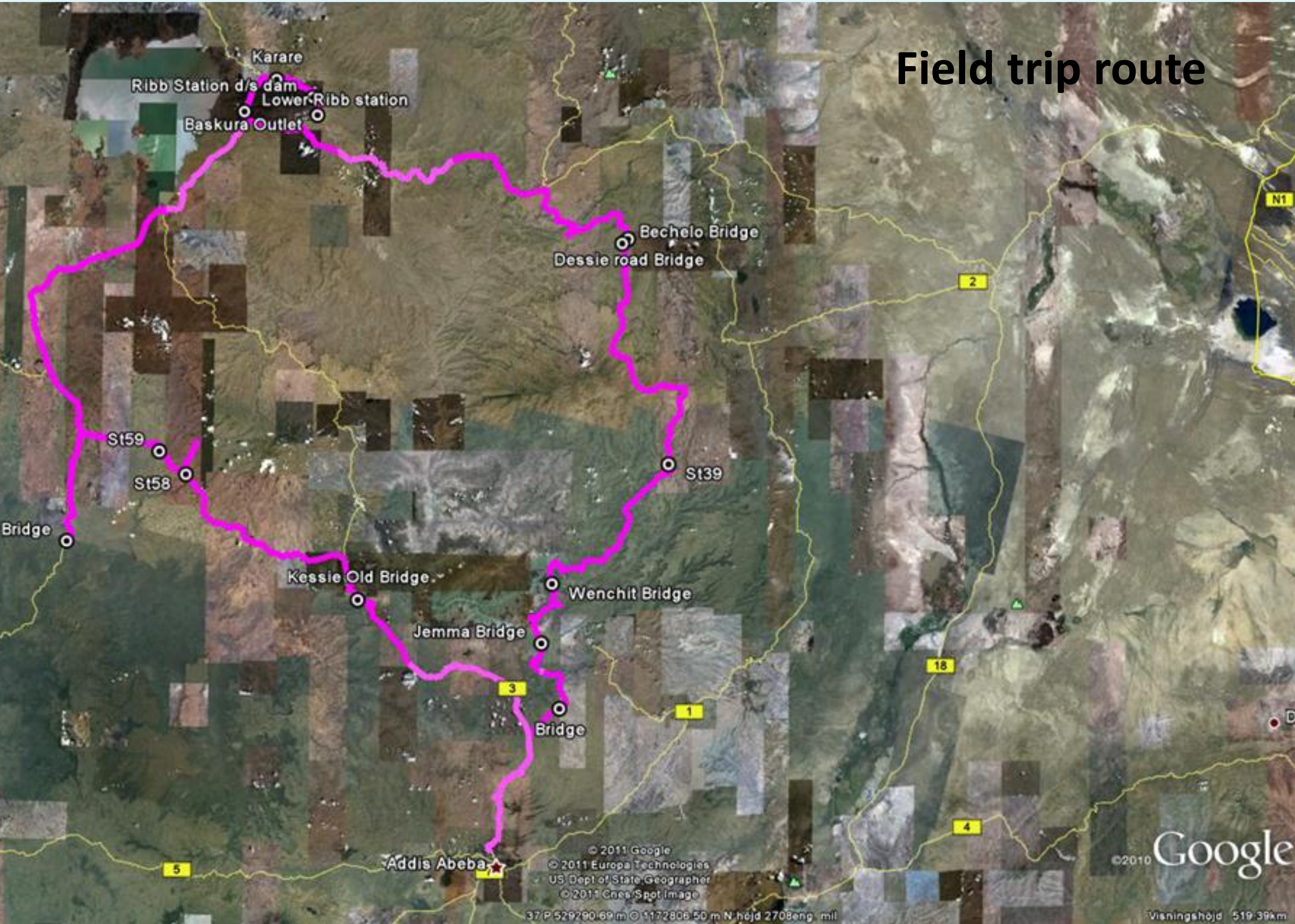
ETHIOPIA: ROAD NETWORKS & RIVER BASINS

Abbay River basin field trip

21-25 July 2011

Photos by
Carsten Staub

Field trip route



Station 30 on the Sibulu River near Chancho

Station 30 on the Sibulu River near Chancho

Kessie Old Bridge

Water level recorder (non-functional)

Kessie Old Bridge
Damaged current meter


Kessie Old Bridge
Dented tail fin

Kessie Old Bridge
Looking upstream towards new bridge

Kessie Old Bridge
Guarded monitoring site

Broken
conical collar

Kessie Old Bridge
Damaged sediment sampler


Kessie Old Bridge

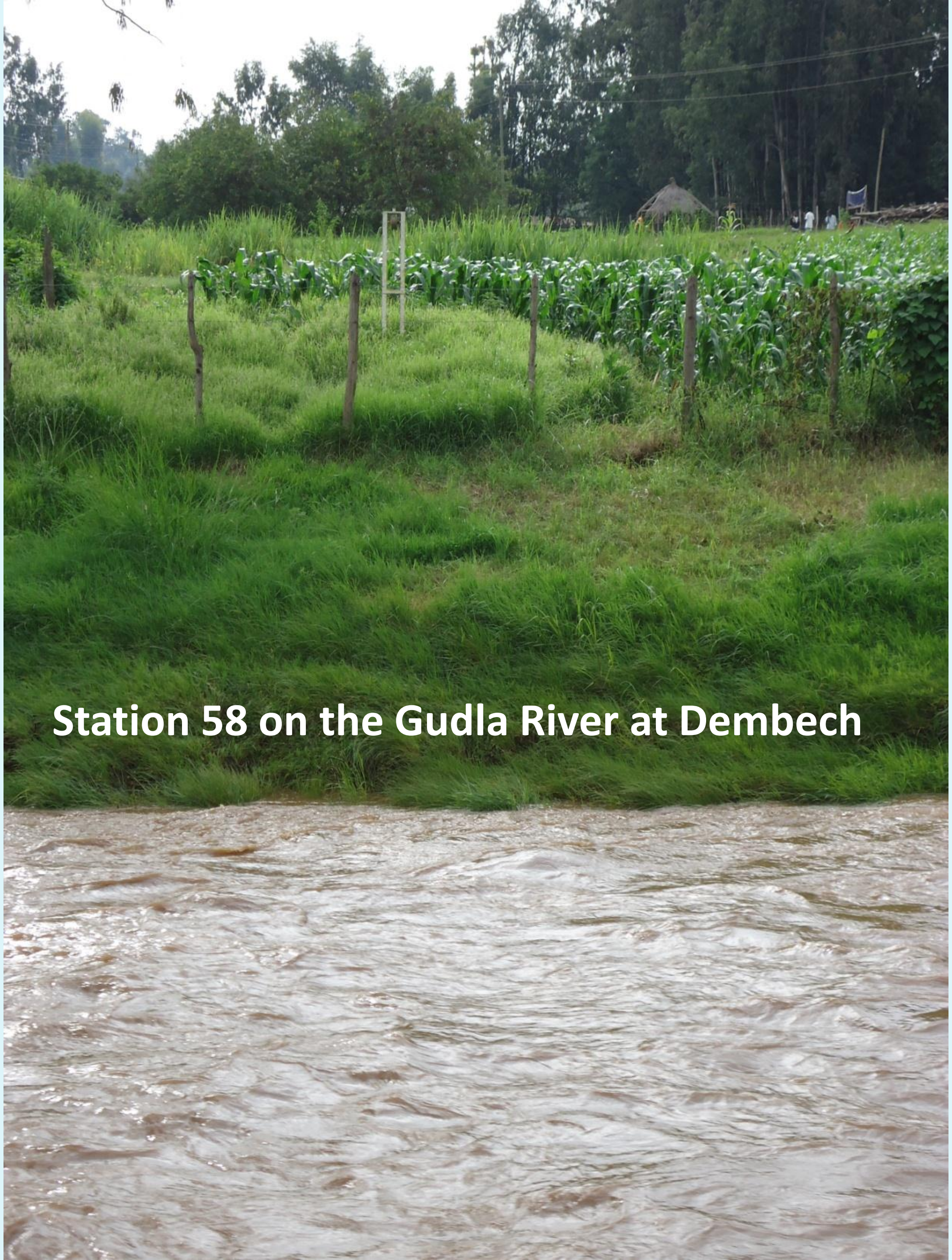
Broken tail

Kessie Old Bridge
Damaged sediment sampler

Kessie Old Bridge
Ultra-sonic water level gauge

Kessie Old Bridge
Ultra-sonic water level gauge

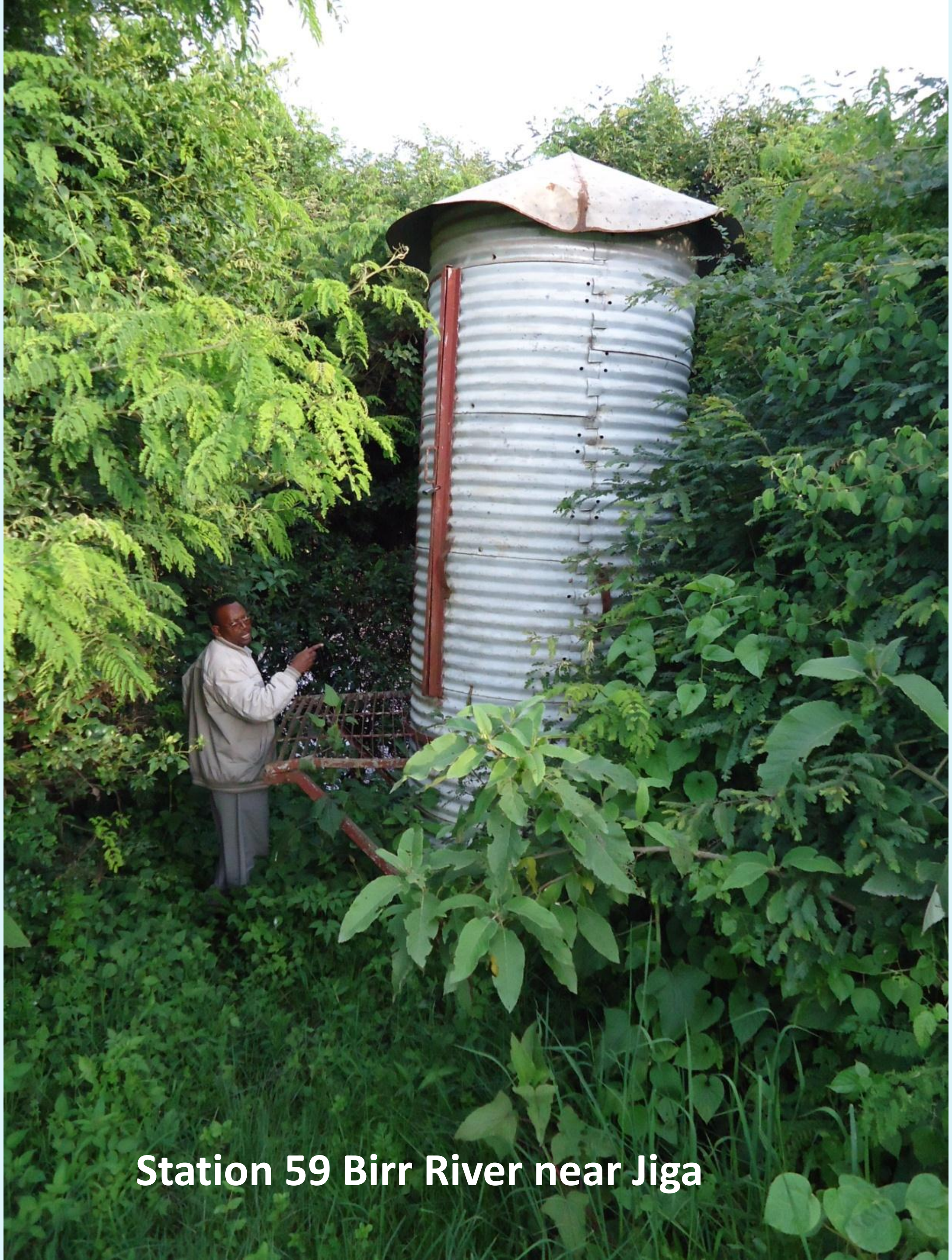
Station 58 on the Gudla River at Dembech



Station 58 on the Gudla River at Dembech

SCRP hydrometric station

Station 59 Birr River near Jiga



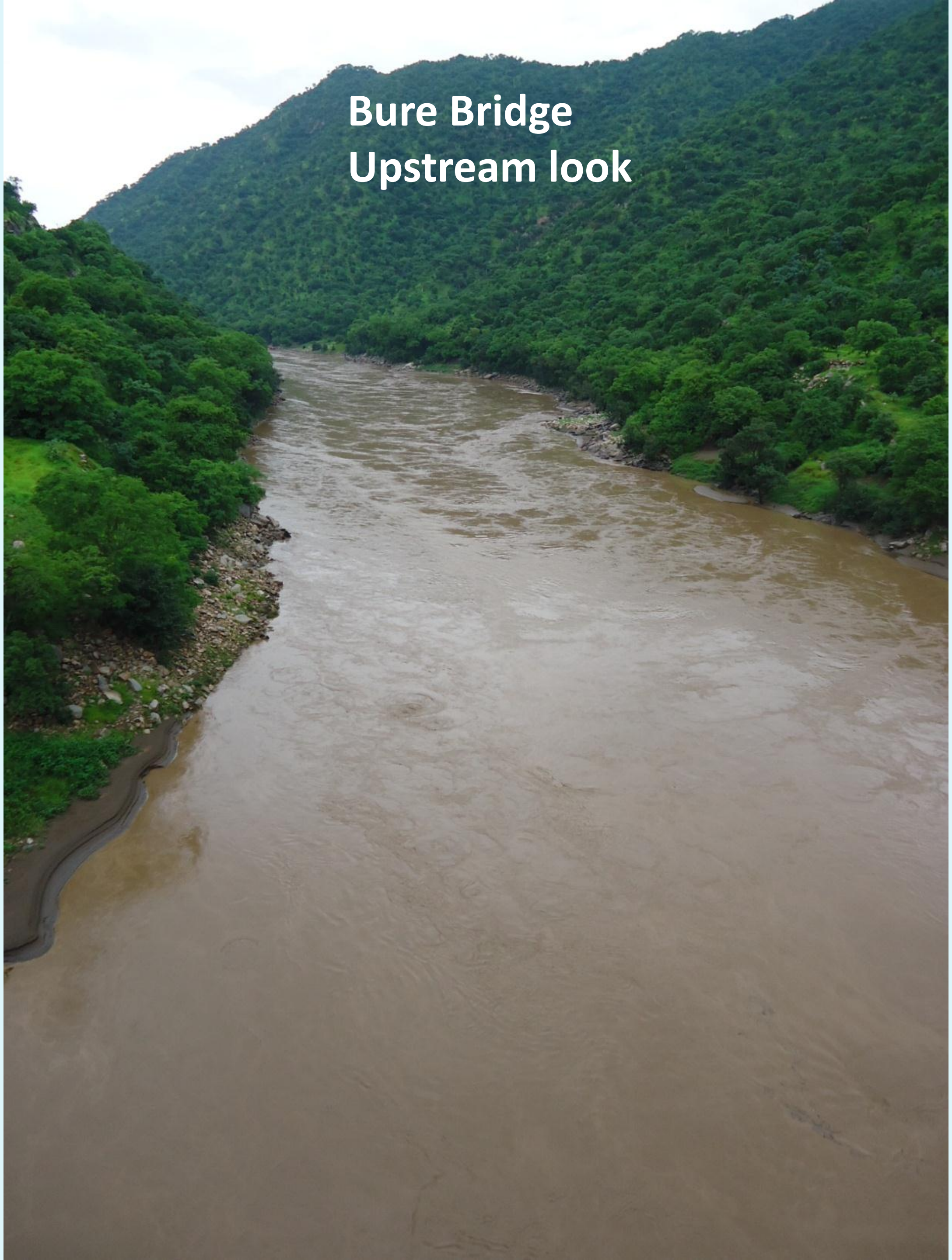
Station 59 Birr River near Jiga

Station 59 Birr River near Jiga

Station 62 Lah River near Finot

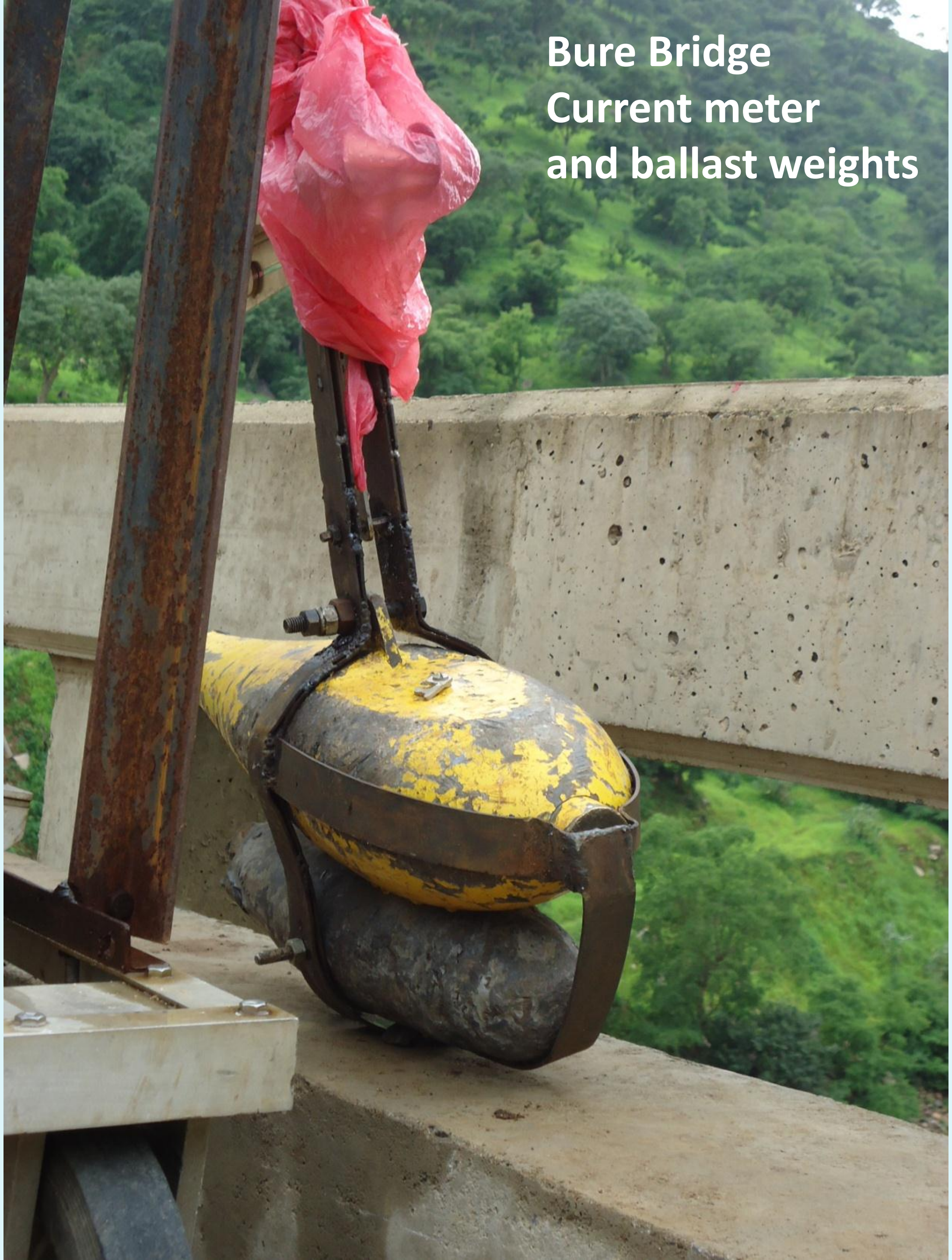
Bure Bridge

Bure Bridge
Downstream look



Bure Bridge
Upstream look

Bure Bridge
Current meter
and ballast weights



Bure Bridge
Sediment sampler

Bure Bridge

Bure Bridge

Bure Bridge

Bure Bridge

GS

Bure Bridge

Bure Bridge

Bure Bridge

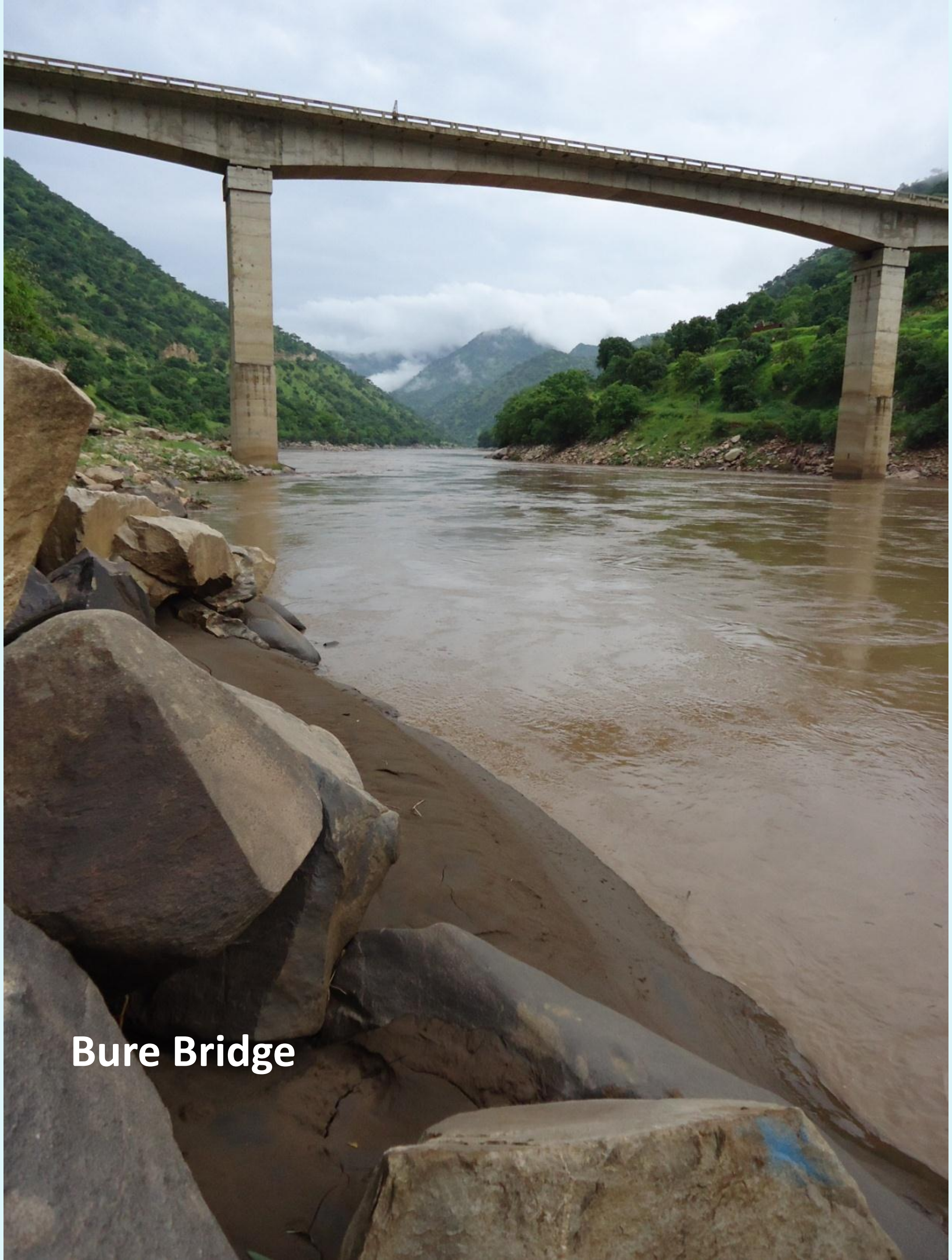
Bure Bridge

Bure Bridge

Bure Bridge


Bure Bridge

Bure Bridge



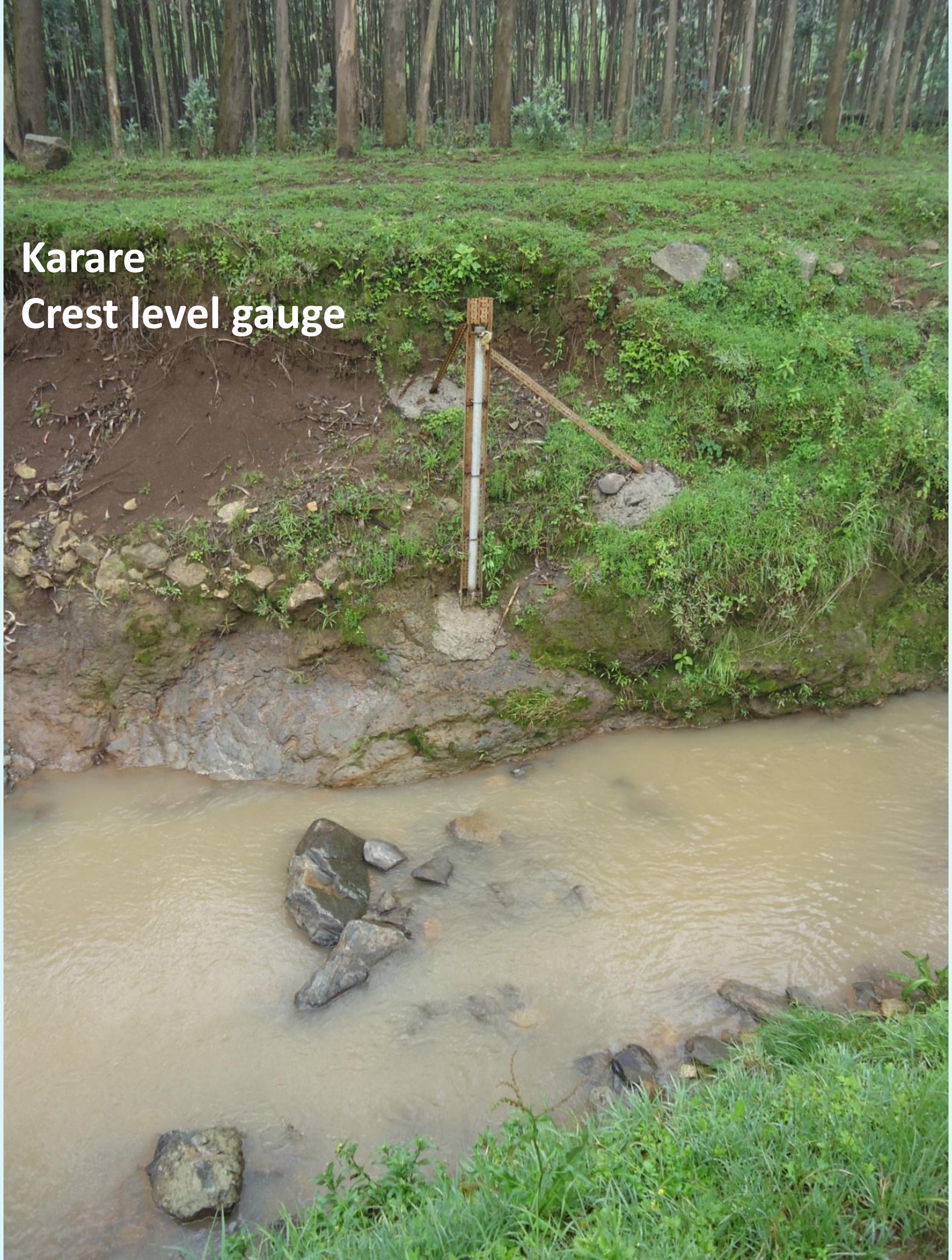
Bure Bridge

Secci turbidity test at Karare

Karare

Karare
Pressure cell water level gauge

Karare
Pressure cell water level gauge


Karare
Crest level gauge

Station 8 d/s Ribb Dam

Station 8 d/s Ribb Dam

Station 8 d/s Ribb Dam


Ribb River
downstream station (5)

Ribb River
downstream station (5)

Gorges North of Beshilo River

Gorges North of Beshilo River

North of Beshilo River

North of Beshilo River

Bechelo Bridge


Bechelo Bridge

Bechelo Bridge

Bechelo Bridge
Erosion attack at left
abutment

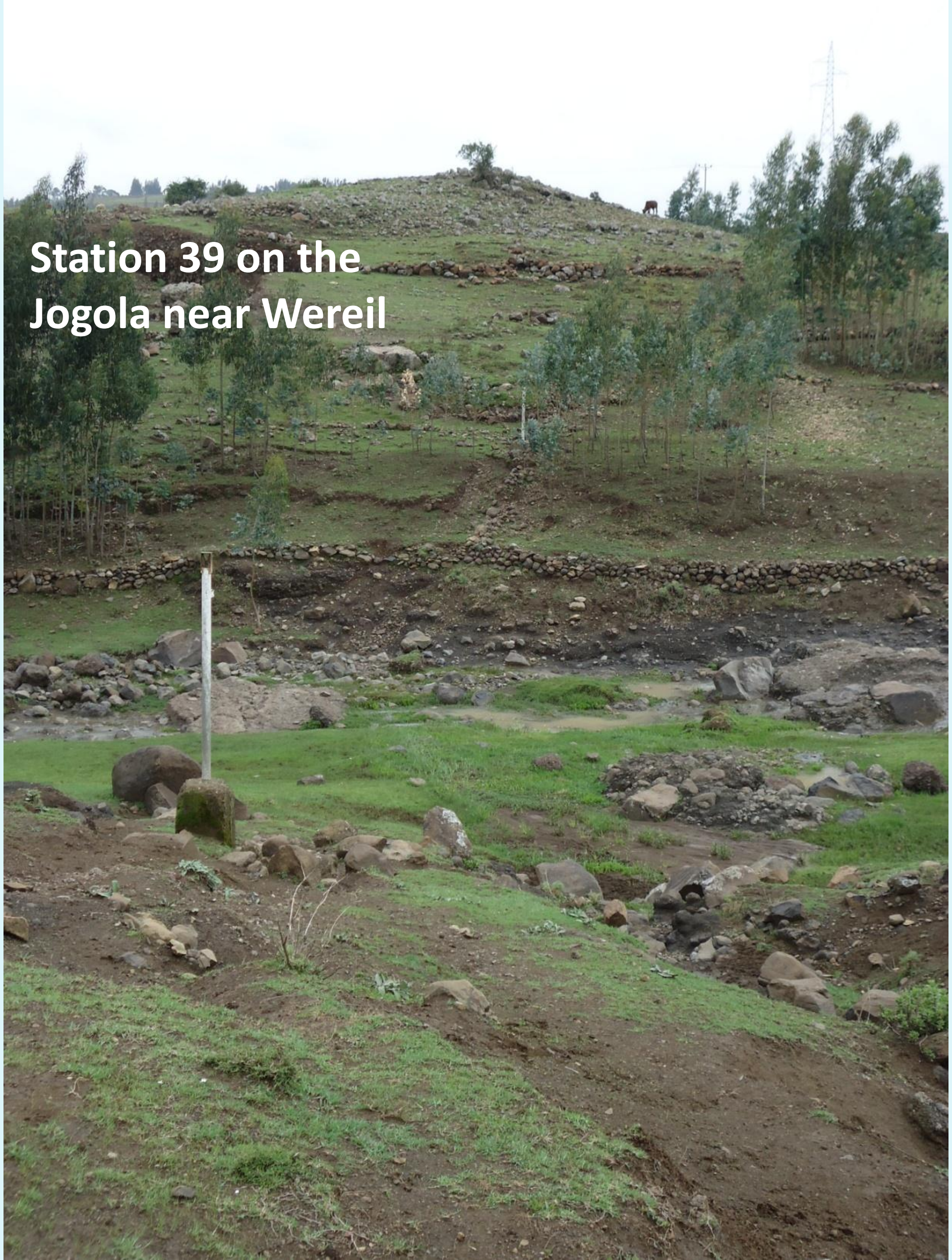
Bechelo Bridge
Upstream view

Dessie Road Bridge
on Tria River
(Bechelo tributary)

Dessie Road Bridge
on Tria River
(Bechelo tributary)

Station 39 on the Jogola near Wereil

Station 39 on the Jogola
near Wereil
Washed away staff gauge



Station 39 on the
Jogola near Wereil


Wenchit
Bridge

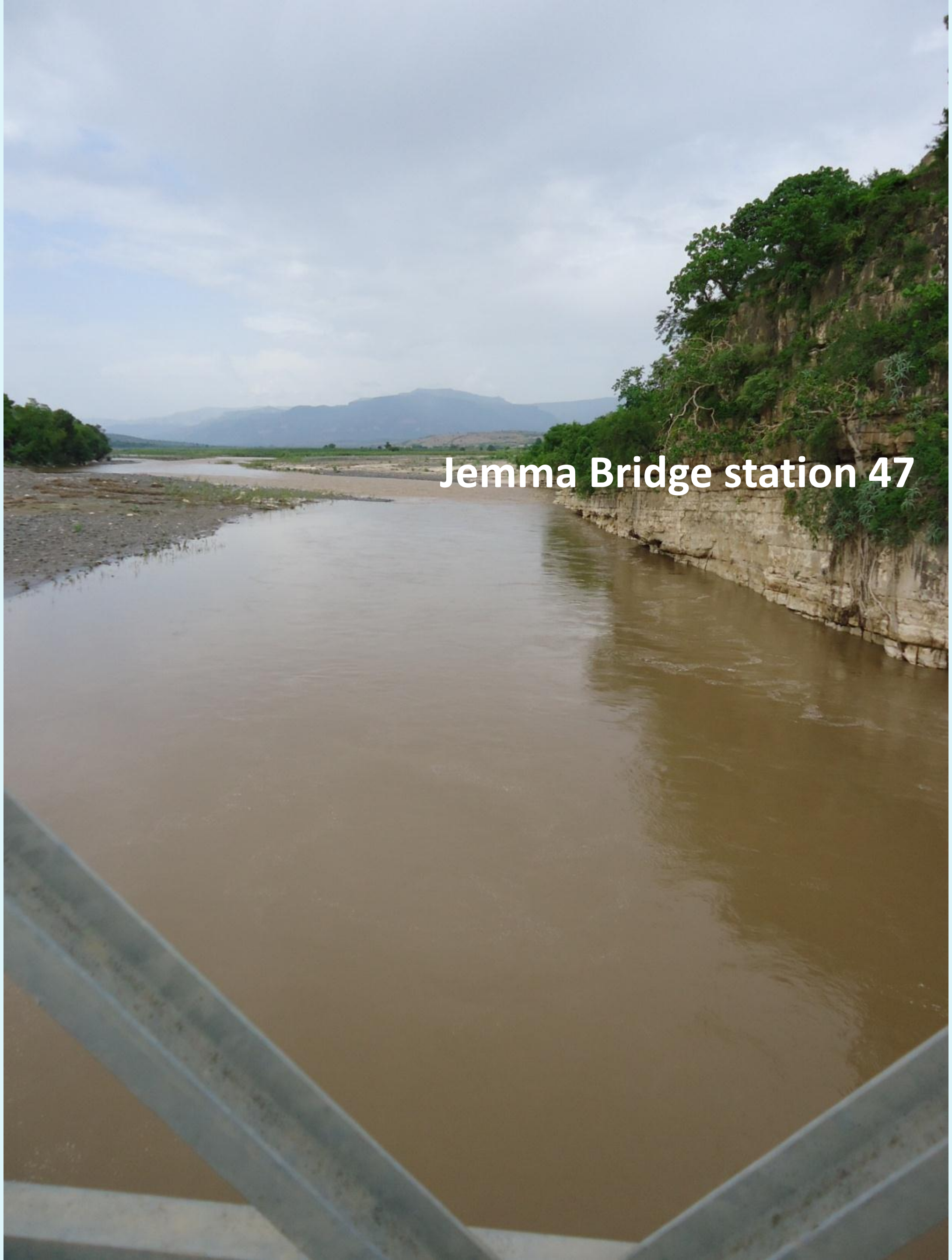

Wenchit Bridge

Wenchit Bridge

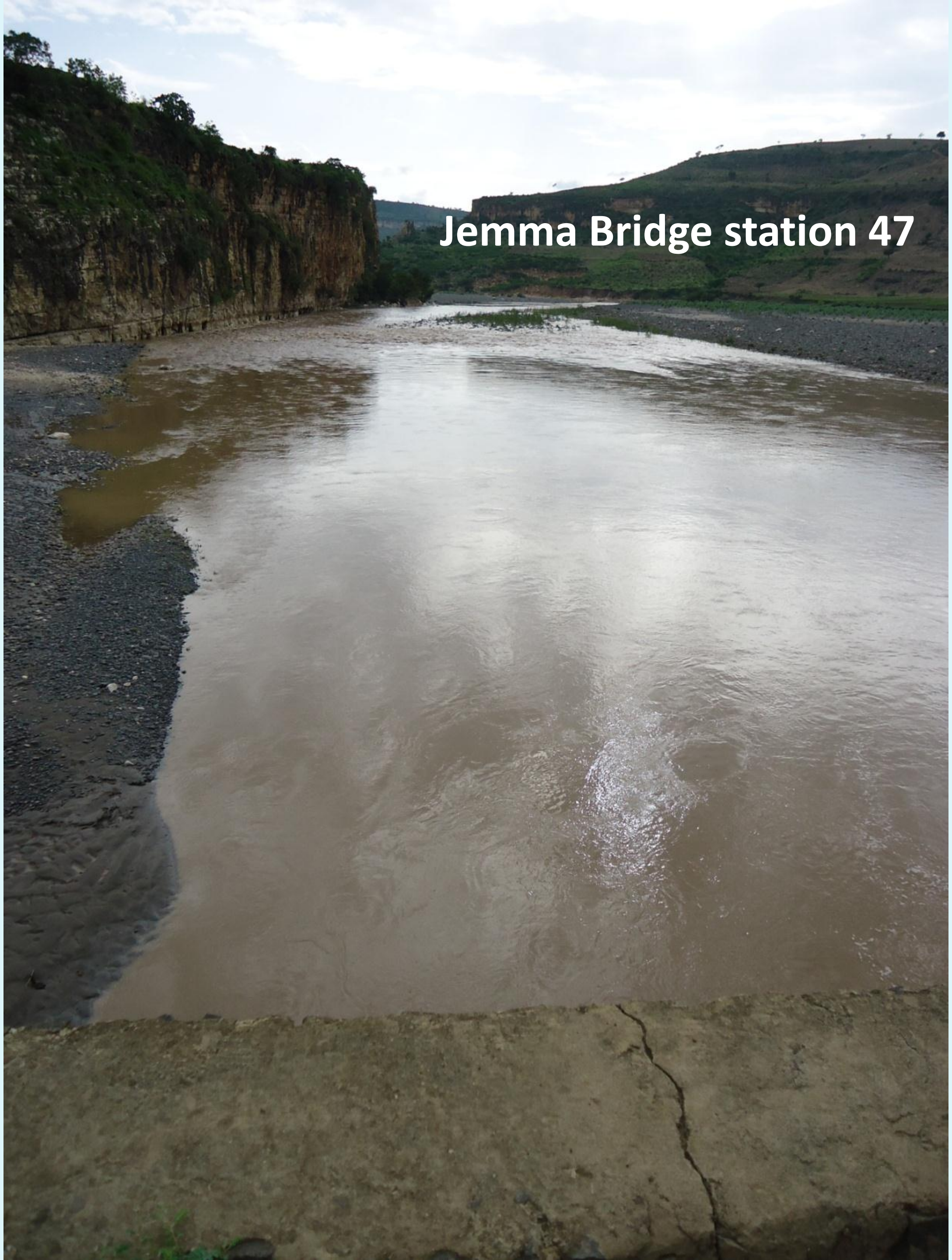

Wenchit
Bridge

Jemma Bridge station 47

Jemma Bridge station 47



Jemma Bridge station 47



Jemma Bridge station 47

Jemma Bridge station 47

Jemma Bridge station 47

Jemma Bridge station 47
Level markings on wall

Tekeze River basin field trip
5-8 August 2011

Photos by
Carsten Staub

Field trip route

Station 3

Straight reach
Sandy river

Station 3

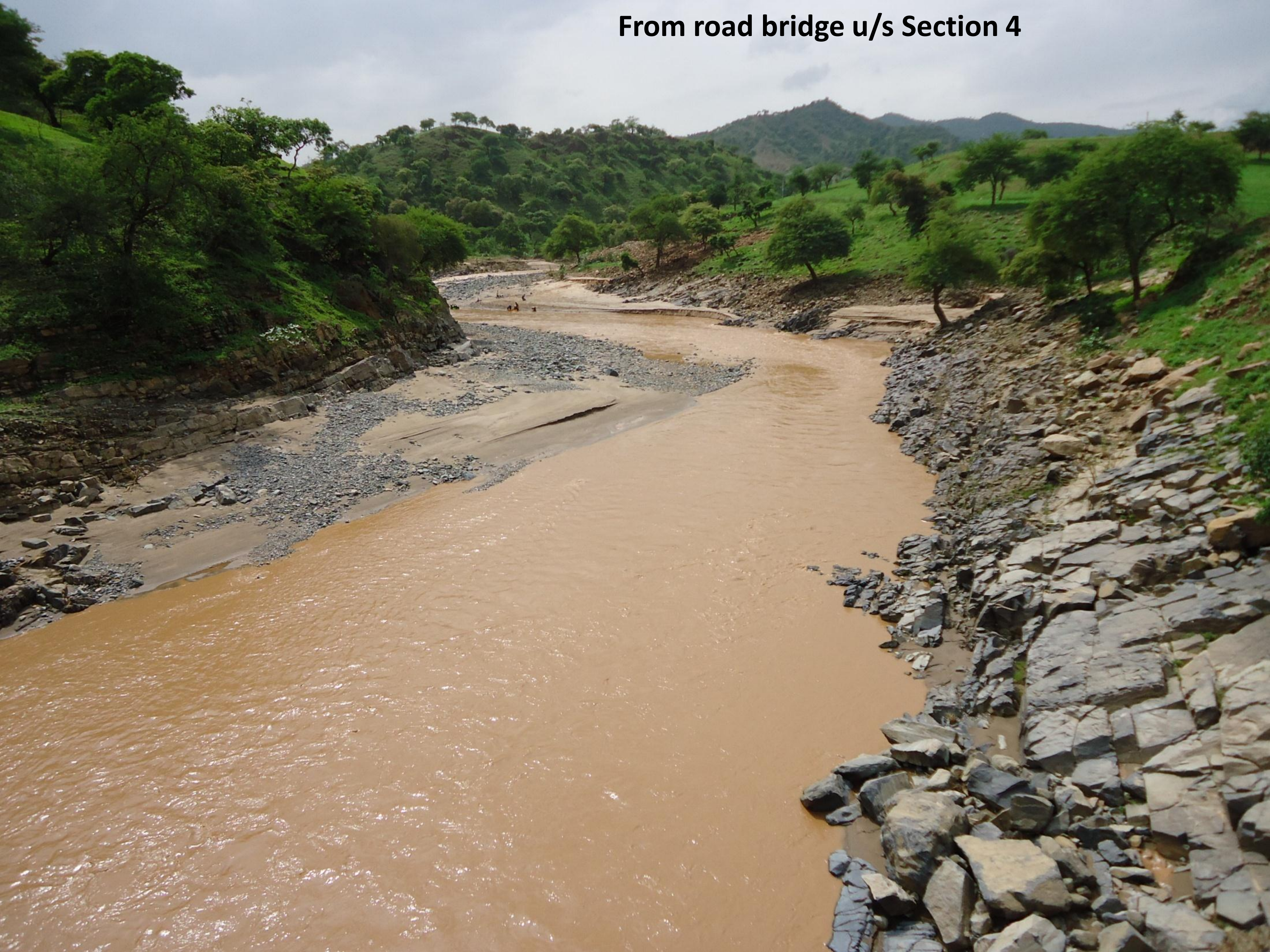
Natural control section d/s

Station 3

Autogauge Non-functional

Station 3

From road bridge u/s Section 4



Entering Tekese gorge towards station 5


Station 5 at bridge


Station 5 at bridge

Station 5
Rapid non-uniform flow along right bank


Station 5
Mid-channel island

Station 5

Ultrasonic water level gauge (non-functional)

Station 5

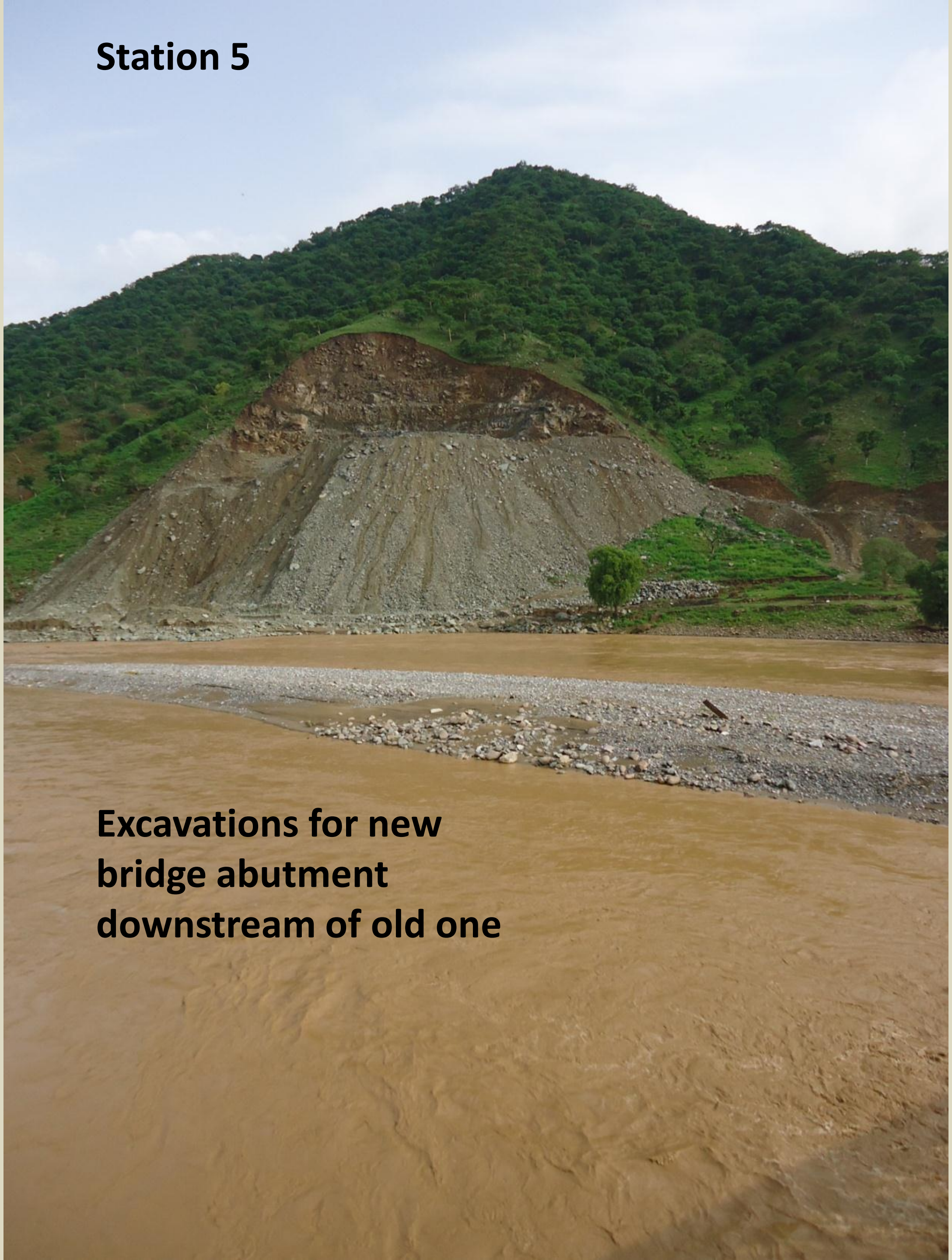
Station 5

Remains of bridge destroyed by flood

Remains of bridge destroyed by flood

Station 5

Station 5



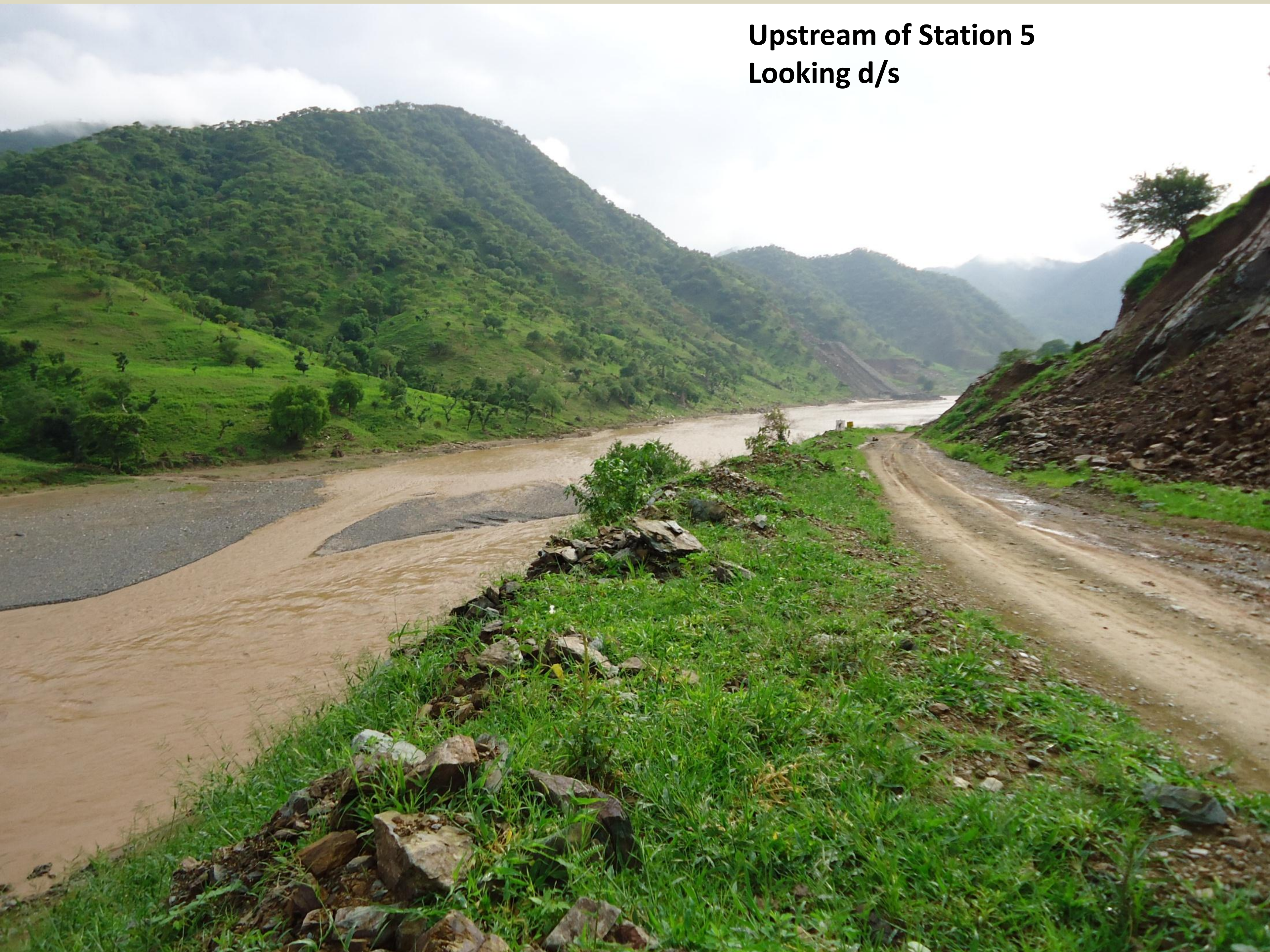
Excavations for new bridge abutment downstream of old one

Station 5

Remains of bridge destroyed by flood

Station 5
Rapid non-uniform flow
along right bank

Upstream of Station 5


Upstream of Station 5
Looking d/s

Initiation of gully erosion close to Station 5

Beginning gully erosion on poorly terraced steep slopes

Backward erosion in gently sloping field

Eroding hill slopes
Close-up

Erosion enhanced by road cutting

Terraced fields with no evident erosion

Station 7

Station 7

Uniform flow
Sandy river

Station 7

Natural control section d/s

Station 7

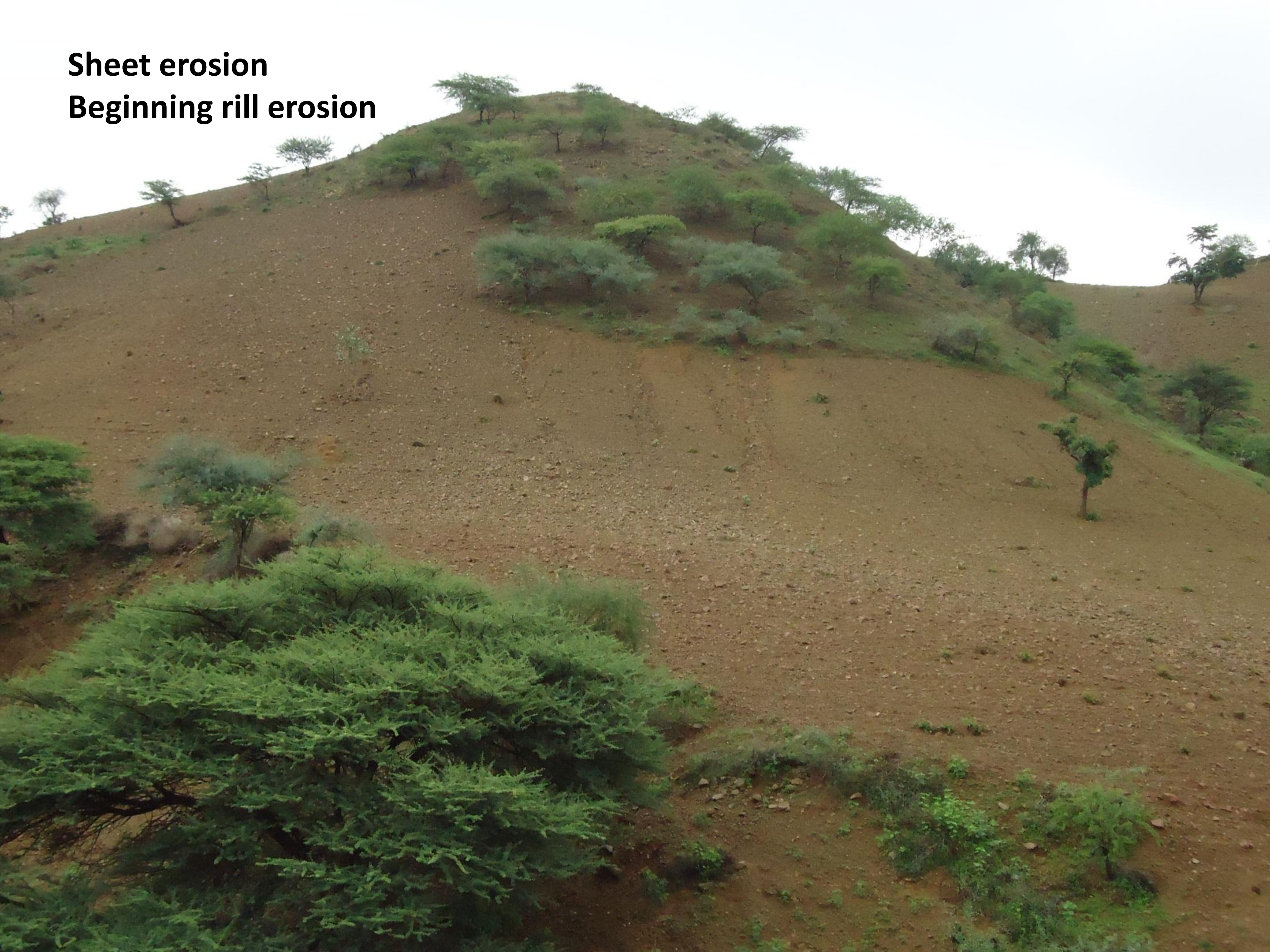
Staff gauge lost
Level markings
on bridge pillar

Station 7

Small right bank tributary u/s

Station 7
Looking d/s

Sheet erosion
Beginning rill erosion



Small sanded up stream close to Station 7

Small sanded up stream close to Station 7

Small sanded up stream close to Station 7

Station 29

Sharp bend upstream
Rocky/gravelly river

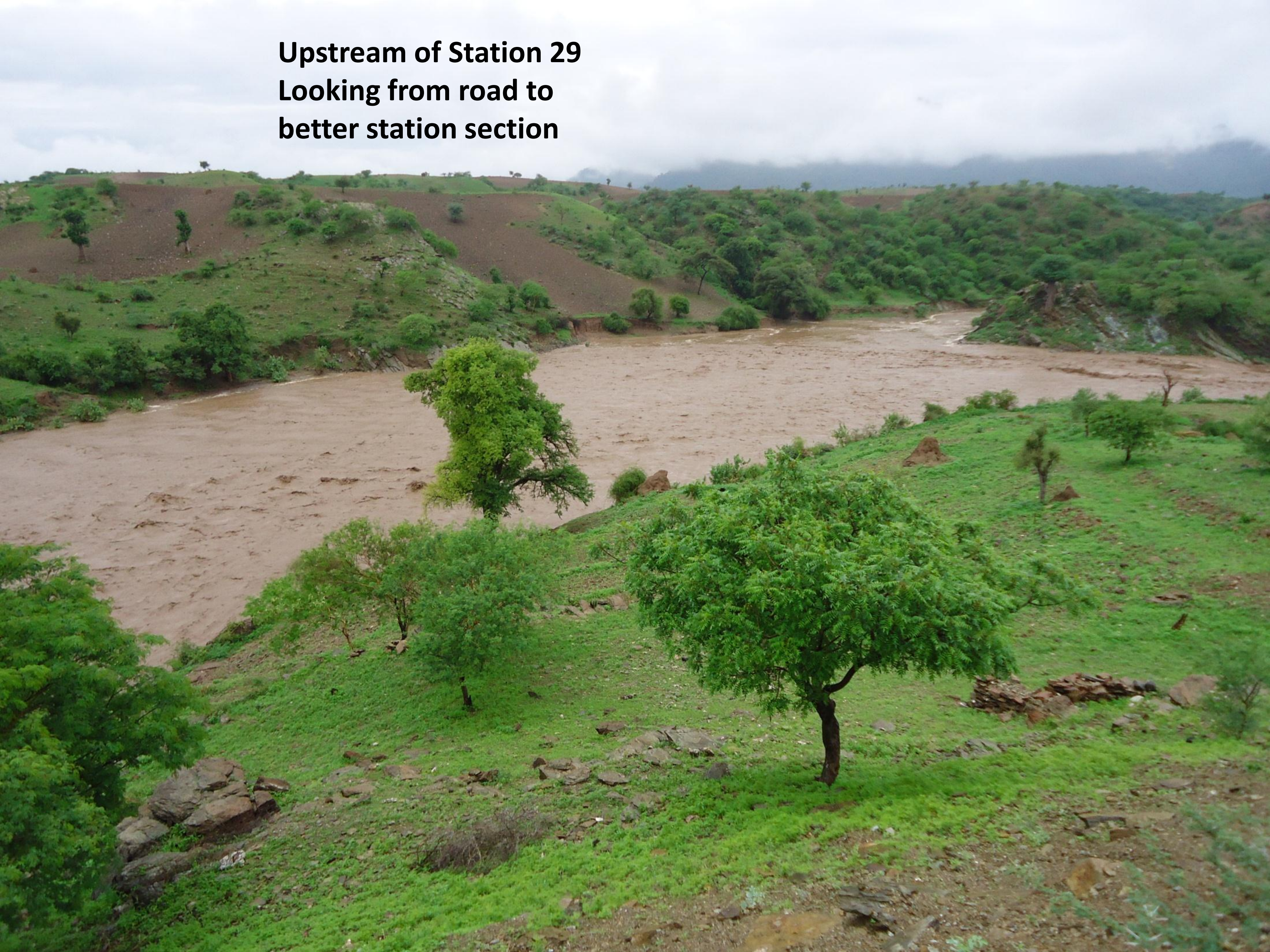
Station 29, looking d/s
Rapid flows

Station 29

Station 29
Looking u/s

Station 29

Station 29



Upstream of Station 29
Looking from road to
better station section

Station 30
Oblique rapid flows

Station 30

Station 30


Station 30

Station 30


Station 30

Station 30 Looking d/s to better section

Station 30

Station 30

Water level measured here

Eroding slopes

Univ of Mekele measuring section in small flashy river

Mekele branch office

Outdoor storage of equipment

Imported winch

Parts of locally manufactured winch