FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA

MINISTRY OF WATER RESOURCES

WATER INFORMATION AND KNOWLEDGE MANAGEMENT PROJECT

COMPONENT 2: STRENGTHENING WATER QUALITY DATA GENERATION AND MANAGEMENT

Draft Final Report

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LIST OF ACRONYMS AND ABBREVIATIONS

ADCP	Acoustic Doppler Current Profile
AWF	African Water Facility
AWLR	Automatic Water Level Recorder
BRA	Basic Routine Analyses
BRLi	Bas Rhone Languedoc ingénierie
BOC	Bank operated cableway
DCP	Data collection platform
DEM	Digital elevation model
EPA	Environmental Protection Authority
FTP	File transfer protocol
GIS	Geographic information system
GPS	Global positioning system
GrW	Ground Water
GSE	Geological Survey of Ethiopia
GSM	Global System for Mobile communication
MoWR	Ministry of Water Resource
NMA	National Meteorological Agency
RBA	River Basin Authority
SuW	Surface Water
ToR	Terms of Reference
WMO	World Meterological Organization

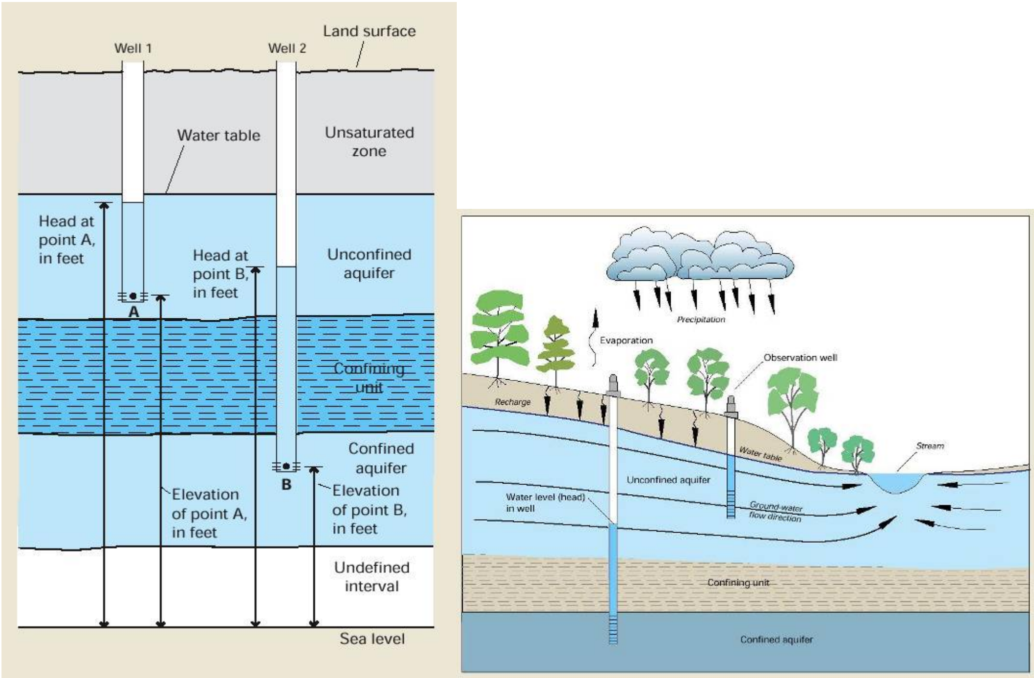

Figure 1 Groundwater terminology

Ground water: Water occurring beneath the ground surface in the zone of saturation.

Aquifer flow type: The principal aquifer flow types are confined and unconfined. Within each of these primary flow types, flow may occur through granular porous media (e.g. sand), through fracture networks in consolidated rocks, or through dissolution channels in consolidated rock.

Confined aquifer: An aquifer bounded above and below by confining beds.

Confining bed: A body of relatively less permeable or distinctly less permeable material, stratigraphically adjacent to one or more aquifers.

Unconfined aquifer: An aquifer in which the ground-water level near the ground-water surface is equal to the ground-water surface. An alternative and equivalent definition is an aquifer in which the ground-water surface is at atmospheric pressure.

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1. Context

1.1 General Geographical Context

Ethiopia, with a total area of some 1,127,000 km², is a landlocked country in East Africa, situated to the west of Somalia and north of Kenya.

The terrain consists largely of high mountains and plateaux with elevations above 1500 m, divided from south-west to north-east by the East African Rift Valley, a major structural feature some 40– 60 km wide and in places 1000 m below the flanking plateau areas.

Elevation in Ethiopia varies from the highest point at Ras Deshen Terara (4620 m) to the lowest in the Danakil Depression (-125 m; northern section of the Afar Depression). The Ogaden region of eastern Ethiopia (bordering Somalia) is also a flat-lying plain, with an elevation of around 600 m ((Figure 2 Map of Ethiopia).

Figure 2 Map of Ethiopia

1.2 Water Resources and Use

FAO information sources

1.2.1 Water resources

Ethiopia is endowed with a substantial amount of water resources. The surface water resource potential is impressive, but few developed. The country possesses twelve major river basins, which form four major drainage systems:

- The Nile basin (including Abbay or Blue Nile, Baro-Akobo, Setit-Tekeze/Atbara and Mereb) covers 33 percent of the country and drains the northern and central parts westwards;
- The Rift Valley (including Awash, Denakil, Omo-Gibe and Central Lakes) covers 28 percent of the country;
- The Shebelli-Juba basin (including Wabi-Shebelle and Genale-Dawa) covers 33 percent of the country and drains the southeastern mountains towards Somalia and the Indian Ocean;
- The North-East Coast (including the Ogaden and Gulf of Aden basins) covers 6 percent of the country.

Figure 3 Map of water resources in Ethiopia

Integrated development master plan studies and related river basin surveys undertaken at the end of the 1990s indicate that the aggregate annual runoff from nine Ethiopian river basins is about 122 km^3. The Abbay, Baro-Akobo and Omo-Gibe basins account for about 76 percent of the total runoff from an area that is only 32 percent of the total area of the country. Most of the rivers in Ethiopia are seasonal and about 70 percent of the total runoff is obtained during the period June-August. Dry season flow originates from springs which provide base flows for small-scale irrigation. The groundwater potential of the country is not known with any certainty, but so far only a small fraction of the groundwater has been developed and this mainly for local water supply purposes. Traditional wells are widely used by nomads. Neither desalinization nor treatment of wastewater is practiced in Ethiopia.

Intense rainfall sometimes causes flooding particularly along the Awash river and in the lower Baro-Akobo and Wabe-Shebelle river basins, causing damage to standing crops and infrastructures. The construction of dykes mitigated the problem but has not provided a long-lasting solution. Ethiopia has several lakes (an area of about 7 000 km^2), a number of saline and crater lakes as well as several wetland areas. All the lakes, except Lake Tana which is the source of Abbay River in the Nile Basin, are found in the Rift Valley and among these lakes only Zway has fresh water while the others are all saline. Rising water levels in Lake Tana and Lake Awassa after intense rainfall have been creating concern. Large wetlands serve as a source of water for large rivers, flood retention and groundwater recharge. They are critical resources because they are areas of high biodiversity and are often vital to the livelihood strategies of local communities through the provision of environmental services and socio-economic benefits. Ethiopia has so far put no emphasis on developing and protecting the large wetlands, although external initiatives are emerging.

Ethiopia has many small, medium and large reservoir dams constructed for hydropower generation, irrigation and drinking water supply. Small dams are less than 15 m high and have a capacity of less than 3 million m^3. The height of the medium and large dams in Ethiopia is 15-50 m and their capacity ranges from 4 to 1 900 million m3. In total, there are nine medium and large dams with a total capacity of almost 3.5 km^3. Two large dams are used for hydropower generation only, one dam is used both for hydropower generation and irrigation supply, two dams are used for irrigation supply only and the remaining four for water supply to the city of Addis Ababa and the town of Gondar. Small dams (micro-dams) constructed for irrigation supply are concentrated in the Amhara and Tigray regional states.

1.2.2 Water use

Detailed written information on water use is not available, but agriculture is obviously the main water-consuming sector. Based on the total irrigated area, cropping pattern and calendar, annual agricultural water use is estimated to be in the order of 5.2 km^3, while municipal and industrial water withdrawals are estimated to be about 0.33 and 0.02 km^3 respectively. There is growing concern about water use because of the conflict between the environment and agriculture particularly in lowland rural areas, where total base flows are diverted for irrigation without releasing water for ecological conservation. Groundwater has not yet been considered for irrigation development, mainly due to high investment and running costs, but pilot schemes to use groundwater for irrigation have been started.

1.2.3 International water issues

Most of the rivers of Ethiopia originate within the country and flow across the borders to neighboring countries, thus becoming transboundary rivers. Sharing the water resources of these transboundary rivers is very challenging, particularly the Nile tributaries (Abbay, Tekeze and Baro-Akobo) with the downstream riparian countries Sudan and Egypt. Recently, under an international law supporting the equitable utilization of the water resources, positive progress has been observed now that riparian countries are deciding on common water development programs. The Nile Basin Initiative has been created and a Strategic Action Program prepared which consists of two sub-programs: the Shared Vision Program (SVP) and the Subsidiary Action Program (SAP). SVP is to help create an enabling environment for action on the ground through building trust and skill, while SAP is aimed at the delivery of actual development projects involving two or more countries. Projects are selected by individual riparian countries for implementation and submitted to the Council of Ministers of the Nile Basin Initiative for approval. The council has already accepted four hydropower and four irrigation development projects proposed by Ethiopia. Sudan, Ethiopia and Egypt have also adopted a strategy of cooperation in which all projects to be launched concerning the river should seek the common benefit of all member states and this aspect should be included in the accompanying feasibility studies.

1.2.4 Policies and legislation

A comprehensive and integrated Water Resources Management Policy, prepared by the MoWR, was adopted in 2000. Some of the guiding principles are: i) recognition of water as a scarce and vital socio-economic resource to be managed and planned strategically; ii) recognition of water as an economic good; iii) stakeholders to be involved in water resources management. Relevant proclamations include:

- Proclamation No 197/2000, stating that all of the country’s water resources are the common property of the Ethiopian people and the state and giving the MoWR the necessary power to allocate and apportion water to all regional states regardless of the source and location of the resource.
- Proclamation No 4/1995, stating that the MoWR has the power and duty to determine the conditions and methods required for the optimum allocation and utilization of the water that flows across or between more than one regional government among various users.

- Proclamation No 41/1993, granting the regions the mandate for certain aspects of water resource management, including small-scale hydropower activities.
- Proclamation No 197/1992, dealing with the water resources management regulations describing development areas that require a license, procedures for obtaining licenses, the allocation of water for various uses and the need to protect water resources from pollution. It considers that water is an economic good and that it has to be valued and deserves protection. A water code is being drafted.

The overall objective of the Irrigation Policy, which is one chapter of the Water Resources Management Policy, is to develop the huge irrigated-agriculture potential for the production of the food crops and raw materials needed for agro-industries in a sustainable way. The policy emphasizes:

- Full integration of irrigation with the overall framework of socio-economic development plans, and more particularly with the Agricultural Development Led Industrialization Strategy,
- Irrigation being an integral part of the water sector and overall water resources development;
- A reasonable percentage of the GDP being committed to the development of irrigation;
- Decentralization and user-based management of irrigation systems, considering the special needs of rural women;
- Developing priority schemes based on food requirements and the national economy;
- Supporting and enhancing traditional irrigation schemes;
- Ensuring the prevention and mitigation of the degradation of irrigation water;
- Establishing water allocation and priority setting criteria;
- Integration of appropriate drainage facilities and environmental sustainability requirements;
- Enhancing greater participation of regional and other stakeholders;
- Promoting fairness and transparency in the management of irrigated agriculture.

Water Resource Sector Strategies have been developed and short-, medium- and long-term Sector Development Programs prepared for the period 2002-2016. These strategies include the financing of water resources management and development; the creation of an enabling environment; transboundary rivers management; stakeholder participation and gender mainstreaming; disaster-prevention and public safety, and environmental health standards.

1.3 ENVIRONMENTAL CONTEXT: BRIEF DESCRIPTION

1.3.1 Surface water

Ethiopia has 12 river basins, 8 of which are River Basins, 1 Lakes Basin and the remaining 3 Dry basins, with no or insignificant flow out of the drainage system. Almost all of the basins radiate from the central ridges that separate the Rift Valley from the highlands of Ethiopia to all directions out of the country.

Basins drained by rivers originating from the mountains west of the Rift Valley flow West into the Sudan, and those originating from the Eastern highland flow East into the Republic of Somalia. Rivers draining the Rift Valley Basins System originates from the adjoining highlands and flow North and South of the uplift in the Centre of the Ethiopian Rift Valley North of Lake Ziway.

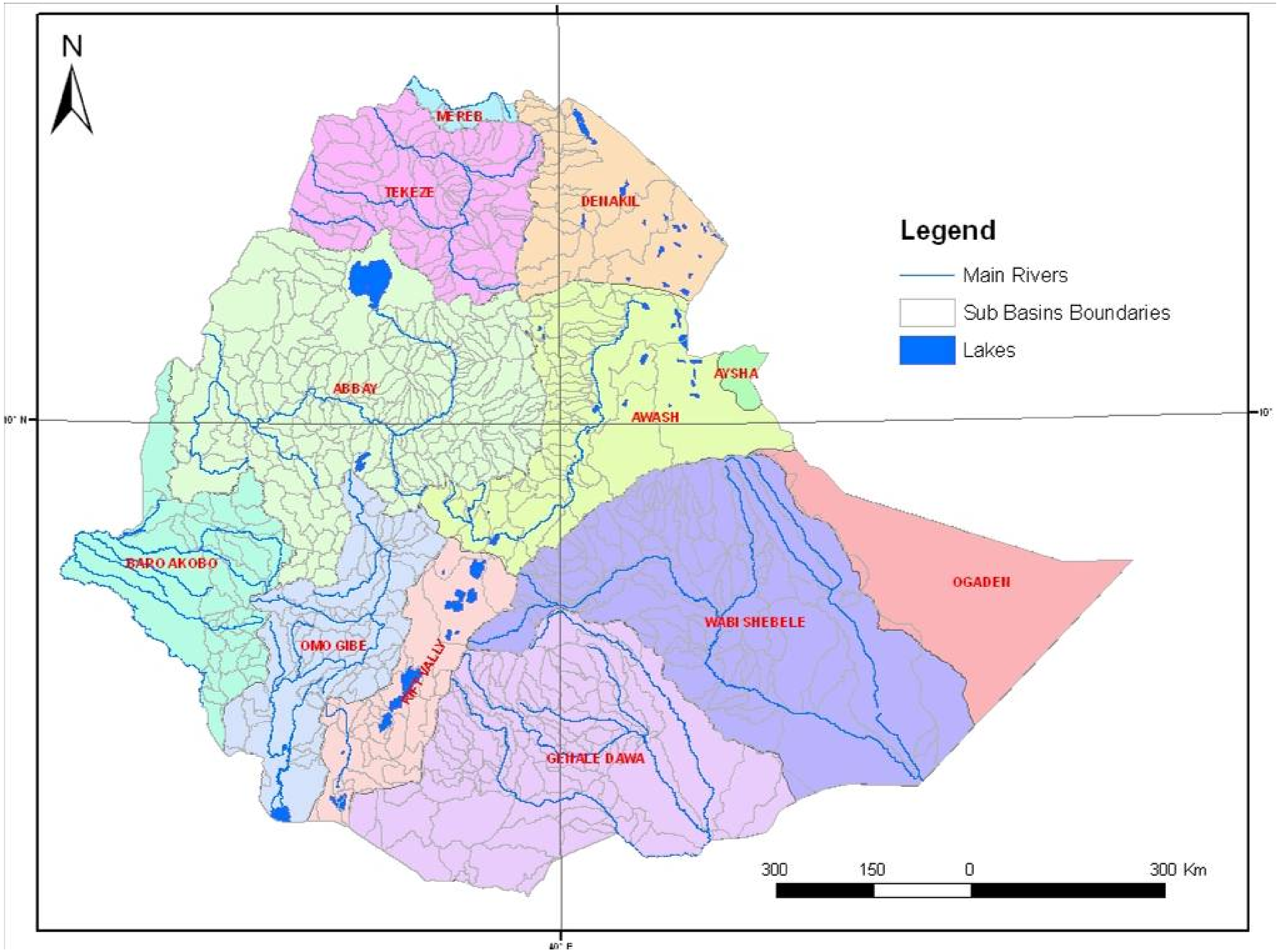


Figure 4 Map of basins and sub-basins

There is very large variation in the size of the Basins. The size of a basin is in mainly function of the geological formation.

Basin Name	Type	Source	Area (km²)	Direction of Flow	Terminal
Wabishebelle	R	Bale Highland	202220	East	Indian Ocean
Abbay	R	West, Southwest HL	199912	West (Nile)	Mediterranean Sea
Genale Dawa	R	Bale Highland	172259	East	Indian Ocean
Awash	R	Central Highland	110000	North-east	Terminal Lakes (Internal)
Tekeze	R	North Wollo Highland	82350	West (Nile)	Mediterranean Sea
Denakil	D	North Wollo Highland	64380	NF	Internal
Ogaden	D	No flow	77120	NF	Internal
Omo-Ghibe	R	Central, Western HL	79000	South	Rudolph Lake Internal)
Baro-Akobo	R	Western Highland	75912	West (Nile)	Mediterranean Sea
Rift Valley Lakes	L	Arsi and Central HL	52000	South	Chew Bahir
Mereb	R	Adigirat HL	5900	West (Nile)	Swamp in Sudan
Aysha	D	No flow	2223	NF	Internal

Source: MoWR Respective Basin Master Plan Studies

HL-Highland D-Dry R-River L- Lake NF-No flow

THE TEKEZE BASIN

Location and size of the basin

Tekeze river basin is situated in the north-western part of Ethiopia and forms the northern most part of the Nile Basin within Ethiopia. It is bordered by the Mereb basin on the north, Danakil basin on the east, Abay basin on the south and the Sudan on the west. The total size of the basin is 86,510 km^2. It covers a total area of 82,350 km^2 within Ethiopia (exclusively in the Amhara and Tigray Regional States). The basin is located between the geographical coordinates of 11 ° 40` and 15 ° 12` N, and 36 ° 30` and 39 ° 50` E. The basin is divided into three sub basins following the three main rivers present in the Basin, namely Tekeze, Angereb and Goang but it is also generally classified into Upper and lower Tekeze basin to refer to the common highland and low land grounds through which all the rivers flow . It is known that about 70 % of the Tekeze basin lies in the highland part of Ethiopia, with a slope ranging from 1.5 to 3 %.

Meteorological and Hydrological conditions

The Tekeze basin consists of three main rivers Tekeze itself, Angereb and Goange. Tekeze rises at an altitude of about 3,500 meter above sea level from the mountain ranges of lasta and flows west, north, then west again until it turns westward along the Ethio-Eritrean border and covering a whole distance of 608 km until it crosses the Ethio-Sudan border near Humera at an altitude of 550 masl. The Angereb river rises in the highlands near Gonder and north of lake tana and it flows west into the Sudan. These river basins join in Sudan and form the Atbara River. Both Tekeze, Angereb and Goang River sub-basins have an estimated annual flow of about 8.20 Bm3.

The Tekeze basin comprises high altitude areas such as the Semien mountains and mount Ras Dashen, which is the tallest mountain in the country, and typical low lands on its eastern sides. As a result the climate of the basin has a remarkable difference between the highland and low lands. Whereas the west region of the basin consisting of the Semien Mountains has a dominantly wet climate, the eastern low lands have both dry and wet seasons. Rainfall decreases from south to north from 1,200 to 600 mm. The mean annual rainfall is 600 mm in the lowlands and 1,300 mm in the Simien Mountains. The mean temperatures in the basin vary from 10 ° C in the Simien Mountains, to 22 ° C in the highlands and to 26 ° C in the lowlands. Minimum and maximum temperature ranges are 3-21 ° C and 19-43 ° C respectively. These climatic differences resulted in the classification of the basin into four agro-ecology zones namely Wurch, Dega, Woina Dega and Kolla.

Land use, population and environmental conditions of the Tekeze basin

Agriculture is one of the fundamental economic activities that provide livelihood for most of the population in the Tekeze basin. The part of the basin area that is used for farming accounts about 27%. Six major types of farming system have been identified in the basin. These are cereal-based single cropping, cereal-based double cropping, irrigated agriculture, commercial farming, agro-pastoral and gum/incense collection systems. These types of farming involve the use of fertilizer and pesticides in the basin. Farming systems, which comprise both crop and livestock productions in mixed farming system are common in the basin. Grain is produced under rain fed using traditional ox-drawn plough by small holder farmers at subsistence level. Average farm size varies from 0.6 to 3.7 ha per household. Future Irrigation Development plans in the Tekeze basin involve the Wolkaite Irrigation project which is expected to cover 40,000ha and the Humera Irrigation project which will cover another 43,000ha of land. The feasibility and detailed design studies of these Irrigation projects are being conducted. In addition, the land use and land cover of the basin includes 35.1% of shrubland, 0.3% of wooded grassland, and 32.5% of bushy/open woodland, shrubby grassland and sparsely vegetated shrubland/exposed rock/soil.

Urban settlements in the Tekeze basin account for 0.16% of the land use type. The important urban settlements in the basin are genrally found in the upper tekeze basin which includes cities and towns such as Gonder, Sekota, Mekelle, Endasellasie, and others. Many other towns and villages are found in close distance from the main or tributary river courses in the upper Tekeze basin. The population of the basin is about 6.4 million in the economic basin area and 4.72 million within the hydrographic boundary. Rural inhabitants are estimated to be about 90%. From the perspectives of impact on water quality, the towns and urban settlements in the low lands may have a secondary importance than the commercial agriculture and Irrigation taking place in lower basin.

Industrial and manufacturing activities are gradually growing in the Tekeze basin. Many small and medium scale industrial activities are established in the regional and zonal capital cities and towns respectively that are found inside the basin. Though not great in number large scale industries are also present in the basin.

Deforestation and soil erosion are the major environmental challenges that are inherently affecting the Tekeze basin. Most of the climax vegetation of the basin has disappeared and only little of the original vegetation is evident while only little of the lowland woodlands and bushlands in the western and northern parts of the basin are nearer to climax. However, the Afro-alpine and sub-afro-alpine heath vegetation lies above 3,700 to 3,900 meter above sea level around Simien Mountains. The river waters in the basin are usually turbid during the rainy season. The important fish species in the basin include Nile Tilapia, Oreochromis Niloticus, African catfish, clarias, gariepinus, Barbus and Barbus intermedius.

Water uses in the Tekeze basin

Like in most other basins the important types of water uses consists of domestic and drinking water uses, for cattle watering, for small and medium scale Irrigations, and recently for hydropower dam. The Angereb dam is a typical example of water use for drinking purposes in the basin. The commissioning of the Tekeze hydropower plant is expected to take place soon.

THE ABBAY BASIN

Location and size of the basin

The Abbay basin is situated in the north-central and western parts of Ethiopia, forming a generally rectangular shape and extending for about 400 km from north to south and for about 550 km from east to west. It starts from the highlands of central Ethiopia and sprawls over to the north and to the west covering a large catchment area. The basin is bordered by the Tekeze basin on the North, Awash basin on the East, Baro-Akobo and Omo-Gibe basins on the south, and the Sudan on the west. The total area of the basin is 199,812 km^2. About 46%, 31% and 23% of the total basin area falls in Amhara, Oromiya and Benishangul-Gumuz respectively. The Abay River basin lies in the west of Ethiopia between 7 ° 45` and 12 ° 45` N, and 34 ° 05` and 39 ° 45` E. The Abbay river basin is generally divided into six sub-basins. These include the Tana sub basin, upper Nile sub basin, middle Nile sub basin, the Dedesa sub basin, Dabus sub basin and lower Nile sub basin. The Tana basin covers an area of some 15,046 km^2.

Meteorological and Hydrological conditions

The Abbay River takes its source in the centre of the catchment and develops its course in a clockwise spiral, collecting tributaries all along its nearly 1,000 km before it reaches the Sudan border. As Gilgel Abbay, it flows to the North into the wide and shallow lake Tana. Then, as Abbay, it flows through a deep gorge. There it receives on its right bank from the Gojam highlands several medium (Abeya, Suha, Chemoga, Birr, Fettam, Dura) and small tributaries, and major ones (Beshilo, Welaka, Jemma, Muger, Guder, Finchaa, Didesa) from the Wello, Shewa and Wellega on its left bank. Before the Sudanese border, it receives in the lowlands its last two tributaries: Dabus from left and Beles, the only major right bank tributary. The Dabus and Didessa are the largest tributaries of the Abbay River accounting for about 10 % and 8.5% of the total flow at the border respectively. The Abbay river has an average annual discharge of about 49.4 BCM (measured at Sudan border). Rgarding the Tana Sub basin, four main rivers flow into the Lake. These are the Gilgel Abbay in the southern part of the Tana basin, the Megech in the northern part, the Ribb, and Gumara, both in the eastern part of the Tana basin. Lake Tana has an area of about 4,070 km2.

The climate in the Abbay River Basin is dominated by two main factors: the near-equatorial location, between latitudes 7º 45'N and 12º 45'N, and the altitude, from 500 m to more than 4,200 m above sea level. The influence of these factors result in a wide variety of local climates, ranging from hot and nearly desert along the Sudan border to temperate on the high plateaux and even cold on the mountain peaks. Annual rainfall varies between 800 to 2,200 mm with a mean value of about 1,420 mm. The mean temperature of the basin is 18.5 ° C with minimum and maximum average daily temperatures of 11.4 and 25.5 ° C respectively. Accordingly, the basin exhibits two main agro-ecology zones namely highland with altitudes above 1500 masl and lowlands below 1500 masl. A three season division is defined for Ethiopia: Kiremt, a rainy season, from June to September; Bega from October to January; and Belg a "small rains" season from February to May. The duration of the different seasons depends on the region. This seasonal pattern determines the annual variation of all climatic parameters. The rainy season (Kiremt) contributes from 50% up to nearly 90% of the annual rainfall. The small rains season (Belg) is only significant in the extreme east of the basin while it is practically not known around lake Tana with less than 10% of annual rainfall during this season. Within the Abbay River basin, rainfall increases with altitude: the low-lying areas are generally drier than the high plateaus and most mountains are wetter than highlands around them; and

Land use, population and environmental conditions of the Abbay basin.

In similarity with the Tekeze basin, the Abbay basin is one of the most densely populated basins present in Ethiopia. The total population in the basin is estimated to be about 14.23 million, out of which about 64%, 33% and 3% are in Amhara, Oromiya and Benshangul-Gumuz respectively. The population density of the area is one of the highest in Ethiopia. For example, the 1990s study made it clear that the population densities in the lowland parts along the western sides of the river basins was as low as 15 persons / km^2 while the central and eastern highland parts of the Abbay and Tekeze basins reached as high as 200 persons/ km^2. Agriculture remains to be the main stay to support the livelihood for most of the population in the basin. The Abbay and Tekeze basins are typical examples of the causal link of population growth, poverty and land degradation. The land used for cultivation in the Abbay river basin accounts for about 34% of the total area of the basin. Future irrigation development plans in the basin include Arjo - Dedesa Irrigation Project, Gumara Irrigation Project, Rib, Megech and Anger Irrigation Projects, as well as Koga Irrigation Project.

There are several urban centers of significance in terms of impacts on water quality in the Abbay basin. Even though the land used for urban settlements only accounts for 0.05% of the basin, the population percentage dwelling in urban areas is about 9.3% of the basin population. Some of these urban centers are found in close proximity to the surface water bodies in the basin. Bahir Dar city is a typical example of this, and its polluting potential to Lake Tana is high unless appropriate safe guards are put in place. Tributaries of the Abbay river also drain not only the vast agricultural fields of the basin but also through many of the villages, towns and cities present in the basin. Though widely distributed across the basin, the industrial and manufacturing activities taking place in the basin are also comparatively significant.

Forest resources remain only in a small area in the extreme southwest and in a number of sites along the highland-lowland divide where they have been either under active conversion to cultivation or are 'protected' from clearing by the unsuitability of the sites for other uses.

Water uses in the Abbay basin

Water use in the Abbay basin involves hydropower generation (e.g: Tis Abbay I and II hydropower plants, the upper Beles hydropower plant which is under construction), Aesthtic and recreational purposes (e.g Lake Tana beaches and Tis Issat Water Falls), , irrigation, domestic and drinking water supply, cattle watering, as well as for Fishery in the lake, reservoirs and rivers. The main fish catches are Barbus and Clarius species.

THE BARO AKOBO BASIN

Location and size of the basin

Baro-Akobo Basin is situated in western parts of Ethiopia. It is bordered by the Abay basin in the north east, Omo – Ghibe basin on the south east and by the Sudan on the north to south west. The basin encompasses a total area of 76,000 km^2. The basin is found between the geographical coordinates of latitudes 5 ° 31` and 10 ° 54` N, and longitudes of 33 ° and 36 ° 17` E. The basin is divided into two sub-catchments which are commonly known as the upper basin constituting the upland high altitude areas and the lower basin comprising the low land plains.

Meteorological and Hydrological conditions

The main river of the basin is the Baro River. This river is joined by three major tributaries namely; Akobo, Gilo and Alwero rivers at different points along its main course. The Baro river is created by the confluence of the Birbir and Gebba Rivers, east of Metu in the Illubabor zone of the Oromia region. Other notable tributaries of the Baro include the Jikawo river. These rivers originate at the eastern highlands or upper catchment of the basin and generally flow towards the west over the border to Sudan. According to the master plan study, the mean annual runoff of Baro Akobo basin is estimated to be about 23.24 Bm ^{3}. There are several other small creeks, streams and rivers in the basin catchment that feed into the above mentioned main and tributary rivers.

The physiographic features of the basin consist of both high altitude upland areas which constitute mainly the eastern parts of the basin and low lands which mainly dominate the western parts of the basin. Owing to these wide differences in altitudes the Baro Akobo basin exhibits a range of climatic and meteorological conditions. The basin master plan report indicates that the annual rainfall varies from about 1,800 mm to over 2,200 mm. The mean annual temperatures in the basin range from about 17.5 °C on the highlands to about 27.5 ° C on the flood plains. The mean maximum temperature ranges from 24 to 35 ° C while the mean minimum temperature varies from 10 to 20 ° C. These temperature variations result in classifying the basin into four agro-ecology zones namely Kolla, Woina Dega, Dega and Wurch.

Land use, population and environmental conditions of the Baro Akobo basin

Unlike most other river basins in the country, land used for farming is comparatively small. The land used for growing crops and fallowing accounts about 7.8% and 5.3% of the basin area respectively. More than 25% of these croplands are occupied by coffee. However, the Baro-Akobo Basin comprises a gross irrigable land of about 631, 000 ha in the lower basin alone. Based on water and land resources, the net area that can ultimately be developed is 480,000 ha. Future development plans have identified part of the irrigation potential available in the Baro-Akobo basin. One of the two medium scale Irrigation Development projects identified by the water sector development program is the Alwero/Abobo irrigation scheme which will cover about 10,400 hactars. This is expected to be implemented during the program horizon of 2002 – 2016GC. Pastoralists and mixed farming that involve cattle breeding plays a vital role for the livelihood of the people in the Baro Akobo basin. The basin contains about 1.2 million cattle, 0.4 million sheep, 0.24 million goats, 0.09 million equines and 1.1 million poultry. Cattle are of primary importance representing about 90% of the total livestock units.

Urban settlements in the Baro Akobo basin are quit scarce. The land used for urban settlements in the basin only accounts for 0.06% of the basin area. Major towns found in the basin include Gambella, Metu, Bench maji, Abobo, Itang, and Akobo towns which are in close distance to the main or tributary rivers. Assosa and Gimbi towns are located at the far ends of the basin that divide it from the Abay basin. According to the master plan study, the population of the basin was projected to be about 2.2 million (about 0.5 million households) in 2000 out of which about 60% are in Oromiya, 11% in Benishangul-Gumuz, 21% in SNNPR and 8% in Gambela Regions. Industrial and manufacturing activities are known to be less common or inexistent in the basin.

On the other hand, the environmental condition of the Baro-Akobo basin is enriched by the natural forest cover as compared to the others. Master plan study report of the basin has indicated that about 29% of the basin areas are covered by forest. The basin contains about 2.2 million ha of different types of forests and these accounts about 60% of Ethiopia's natural evergreen forests. The basin is also rich in fresh water resources. Studies have indicated that 100 fish species were found to exist in the lower Baro-Akobo plains. Nile Perch, Nile Tilapia, catfish, Bagrus, Barbus and Labeo species are the most important both in ecological and commercial terms.

Water uses in the Baro-Akobo basin

The major types of water uses envisaged in the Baro Akobo basin consists of domestic and drinking water uses, cattle watering, fishery, small scale irrigation, and for transportation. The Baro and Gillo rivers are one of the most navigable rivers in the Country. So far the rivers of the basin are not yet developed for hydropower generation or for other recreational and aesthetic purposes.

AWASH RIVER BASIN

Location and size of the basin

The Awash River Basin drains the northern part of the Rift Valley in Ethiopia. The basin is bordered on its western side by the Abbay River basin, to the south-west by the Omo-Gibe and Rift Valley Lakes Basin and to the south-east by the Wabi Shebele River Basin. On the east of the Awash River are terminal lakes in the Aysha Dry Basin, the Republic of Djibouti, and the Somali Republic. The basin lies between longitude 7°52′12″ N and 12°08′24″ N and latitude 37°56′24″ E and 43°17′24″ E. The Awash Basin covers a total area of 110,000 km². The Rift Valley area is seismically active and there is a well documented history of earthquakes in the Awash Basin. The Awash River Basin is divided into seven physiographic sub basins. These are the Upland basin, the Upper, Middle and Lower Valleys, the Eastern catchment, the Lower Plains and the Western Highlands.

Meteorological and Hydrological conditions

The Awash River rises on the high plateau to the West of Addis Ababa, at an altitude of about 3,000m. It first flows east draining the Becho Plains and is joined by a number of tributaries before entering the Koka Reservoir. Water released from Koka descends into the Rift Valley and gradually turns northwards, flowing at a much reduced gradient along the base of the western highlands. The Awash is fed by several major tributaries from these highlands. The tributaries include Kessem, Kebena, Awadi, Arso, Ataye, Borkena, Cheleka, Mile and Logiya Rivers. After receiving contributions from the last two tributary, Awash turns abruptly eastwards and terminates in a series of lakes. The large expanse of catchments to the East of the river, accounting for some 40% of the total Basin area, does not contribute any surface runoff to the river. The catchment loses all runoff in to the vast expanse of desert plains which stretches from the escarpment northwards to the terminal lakes. The total length of the Awash River is approximately 1 250km. The Awash basin consists of two small lakes that can have an impact on its water quality. The first one is Beseka Lake and it is found in the upper valley of the basin. Beseka lake is highly saline and it is located within a short distance from the river. The second is Gedebassa Lake and it is found in the middle valley part of the basin in close distance to the main Awash River course.

The climate of the Awash Basin is influenced by the Inter-Tropical Convergence Zone (ICTZ), a zone of low pressure that marks the convergence of dry tropical easterlies and moist equatorial westerlies. As this zone migrates northwards across the basin it causes the small or spring rains in March and at its northern most position (attained in June/July) it results in the heavy summer rains. Its subsequent movement southwards during August, September and October restores drier weather which prevails until the following spring. The mean annual rainfall varies from about 1,600mm at Ankober, in the highlands North East of Addis Ababa to 160mm at Asayita on the Northern limit of the Basin. The mean annual rainfall over the entire Western catchment is 850mm. Given the difference in altitudes, the temperature varies considerably within the basin. The mean annual temperature in Addis Ababa is 16.7°C compared to nearly 30°C at Dubti.

Land use, population and environmental conditions of the Awash basin.

Awash River is comparatively one of the most utilized rivers in the country. Irrigation constitutes one of the important land uses in the basin. The master plan study report indicates that some 200,000ha of suitable land could be available for irrigation. At the time of the initial basin study the irrigated area in the Basin was stated to be 24,300ha. The net area currently commended by irrigation schemes in the Upper, Middle, and Lower valleys is estimated to 69,000ha which is fairly distributed between the three zones, with slightly less in the Middle Valley. Approximately 82% of the irrigable area is farmed by public owned enterprises and the remaining 18% is farmed by commercial farmers. Some three percent of the land is known to have been abandoned as a result of salinity problems and a further 4% is suspected to be uncropped as a result of salinity or poor drainage. Within the Awash Basin, four main farming systems have been identified, defined by the main types of farming activity, agro-climatic conditions, natural resources and settlement characteristics. They include: (i) mixed crop-livestock farming; (ii) large and small-scale commercial irrigated farming enterprises; (iii) agro-pastorialism; and (iv) pastorialism systems. With in the Upper Basin and uplands area cattle predominate and the small herds normally limited to 3-5 tropical livestock units (TLU) per family. In the Upper and Middle valley the individual livestock herds and flocks are larger with less pressure for draught power requirements as rain fed cropping becomes marginal. In the lower valley, where dessert and semi-dessert conditions prevail, only very low stocking rates can be obtained by transhumant grazing. Goats and camels dominate the livestock populations.

Kesem & Tendeho irrigation projects are found in the Awash Basin. A total of 90,000ha Irrigation area with all its infrastructure & Dams design completed. With in the coming one year it is assumed that all of its construction works will be completed.

The overall population in the Awash basin is estimated to be 9,295,530 out of which about 37.5% of the basin are in Oromiya, 18.7% in Amhara, 9.9% in Afar, 7.5% in Somalia, 22.7% in Addis Ababa and 2.7% in Dire Dawa. The main population centers lie in the upper basin and in the upland areas above 1500m elevation. In the upland the main population centers are concentrated along or close to the watershed with the Blue Nile Basin, the larger towns being Debre Sina, Kombolcha and Dese. In the eastern catchment the main town is Dire Dawa. Many of the industrial hotspots in the country are found inside the Awash basin. These include the Industrial corridor extending from Addis Ababa to Nazreth town, Kombolcha area, Wonji and Metehara area, and Diredawa city.

Water uses in the Awash basin

The Awash River serves multipurpose uses all along its course throughout the basin. The Awash River and its tributaries are sources of drinking water for large and small cities such as Addis Ababa, Nazreth, Awash town and Metehara town. Addis Ababa is supplied from three reservoirs (Dire, Legadadi and Gefersa) in the Awash Basin plus a number of other sources. As a matter of fact it is also the source of drinking water for the majority of the people in Afar region. Awash River is also used for generating hydropower energy in Koka 1 and 2 hydropower plants. The Awash River water is also used for industrial consumption and irrigation purposes.

OMO - GIBE RIVER BASIN

Location and size of the basin

Omo-Ghibe Basin is situated in the southwest of Ethiopia between the latitudes of 4 ° 30` and 9 ° 30`N; and longitudes of 35 ° and 38 ° E. The basin has an area of about 79,000 km2 with about 25% falling in Oromiya and the balance in SNNPR. About 51% of the basin area falls in the lowlands. The basin divides sharply and almost exactly into highlands in the northern half and lowlands in the southern half. The northern highlands are deeply dissected and drained by the Ghibe and Gojeb river systems merging to form the Omo in a deeply entrenched gorge. According to the Statistical Abstract of Ethiopia, the Omo River is 760 kilometers long in its course. The Omo has a total fall of about 6000 ft (2,000 m), from an elevation of 7600 ft at its source to 1600 ft at lake-level, and is consequently a very rapid stream, being broken by the Kokobi and other falls, and it empties into Lake Turkana..

Meteorological and Hydrological conditions

The Ghibe River rises on the Ethiopian Plateau just north of latitude 9 ° N at an elevation of about 2,200 masl. The Ghibe River is called the Omo River in its lower valley south and south westwards from its confluence with the Gojeb River. The Ghibe and the Gojeb drains the north and the west of the basin respectively. Its course is generally to the south, however, with a major bend to the west at about 7° N 37° 30' E to about 36° E where it turns south until 5° 30' N where it makes a large S- bend then resumes its southerly course to Lake Turkana. It’s smaller tributaries include the Dinchya and Wabi river. The northern part of the basin has a number of tributaries from northeast of which the largest are Walga and Wabe Rivers. Tuljo and Gilgel Ghibe Rivers are important rivers that drain the main cultivated lands. There are other important rivers, which flow southward towards Omo river/Lake Turkana Trough.

As climate is associated with altitude, the highlands have cool climate with moderate temperature and sufficient rainfall while the lowlands have harsh climate of high temperature and low to medium rainfall. Annual rainfall varies from 400 mm in the extreme south lowland to 1900 mm in the highland with the average being 1140 mm. The mean annual temperature in the basin varies from less than 17 ° C in the west highlands to over 29 ° C in the south lowlands. Based on the altitude and temperature, the basin can be classified into four agro-ecology zones namely, Wurch, Dega, Weina Dega and Kolla.

Land use, population and environmental conditions of the Omo-Gibe basin.

The population of the basin was 6.4 million in 1994. In regards to land use, the highlands are used primarily for cultivation sometimes mixed with grazing (agro-pastoral) or tree (agro-silvicultural). Silvicultural land uses coincide with the contiguous forest areas and pastoral land uses with grassland areas. The potential for irrigation by harmonizing both land and water resources are estimated to be only 90,394 ha. The land cover types of the basin consists of cultivated lands including fallow (28.6%), forestlands (13.5%), woodlands (28.8%), grasslands (15.7%), and bush and shrub lands (13.4%). Some two-thirds of the total forest area can be classified as contiguous forest of significant importance both for watershed protection, soil conservation and timber.

The major types of forests in the basin are broad-leafed forests with about 722,000 ha and riverine forests covering about 110,000 ha. Some 1,500 ha of coniferous forests and 1,500 ha of afro-alpine formation are also found in the basin. About 121,500 ha of land consist of plantation forest and fallow land. The industrial forest development areas contain a large number of high quality timber species.

Many animals live near and on the river, including hipopotamuses, crocodiles and Bitis Aritians. The Omo also flows past the Mago and Omo National Park, which are known for their wildlife. Edible fish occur in all major rivers and tributaries throughout the basin including the Lake Turkana that lies within Ethiopia. It has been indicated that there are 69 fish species in the basin out of which 21 are considered potentially of commercial importance. Out of the latter, 13 inhabit in stagnant or slow running waters with developed macrophytic vegetation. Some of the commercially important fish species are Tilapia, Nile Perch, Barbus and others.

Water uses in the Omo-Ghibe basin

The Omo-Gibe basin has become increasingly important for its hydropower generation potential. Gibe I and II hydropower plants are already developed in the basin. A third and huge hydropower station, Gibe III, is in process to commence its construction and development.

THE MEREB BASIN

Location and size of the basin

The Mereb River basin is situated between latitudes of 14 ° 03` and 14 ° 52` N and longitudes of 37 ° 51` and 39 ° 27` E. The basin covers an area of about 5,893 km2 in Ethiopia all falling in Tigray. The basin has 28 tributaries and 10 small catchments with mean annual flow of 650 Mm3.

Meteorological and Hydrological conditions

The northern area of the Mereb basin has a hot semi-arid climate with mean annual temperature of between 18-27°C and a mean annual rainfall in the range of 410-820 mm while the central portion has a tropical rainy climate with mean annual temperature of the coldest month being 18°C and the mean annual rainfall averaging between 680-200 mm. The southern part has a cool/semi-arid climate with mean annual temperature of 12-18 ° C and mean annual rainfall of 400-620 mm.

Land use, population and environmental conditions of the Mereb basin.

The basin population is estimated to be about 1,030,613 out of which about 5.3% live in urban area and the balance in rural area. The land cover of the basin consists of 26.2% of cultivated land, 14.7% of sparsely vegetated/exposed soil, 14.3% of open shrub land/shrubby grassland, 40.7`% of open shrubland/open bush land and 4.1% of open bushy woodland. The vegetation formation in the basin is characterized by open woodland, open shrubland and open bushland with the first containing deciduous trees with tall grasses dominating as under storey.

Two main farming systems have been identified. These are seed farming complex and irrigation system. The former is cereal-based single, rainfed cropping system and is widely practiced in different agro-ecological zones particularly in the highland and midland areas. Small-scale traditional irrigation is practiced along the small stream for the production of fruits and vegetables.

Rift Valley River Basin

Location and size of the basin

The basin covers a total area of approximately 52,000 km^2 and is shared administratively between two Regional States, Oromia and Southern Nations, Nationalities and Peoples Region (SNNPR).

Meteorological and Hydrological conditions

Both rainfall and temperature vary as a function of elevation. Annual rainfall varies from approximately 300 mm at Chew Bahir in the southern, flat valley bottom of the RVLB, through approximately 550 mm near the somewhat higher elevation northern lakes, to approximately 1600 mm at 3000 masl on the valley sides. Average temperatures vary from approximately 27 degrees centigrade on the valley floor to 10 degrees centigrade at 3000 masl.

The Rift valley river basin comprises three primary sub basins described by their main lake systems, the first comprising lakes Ziway, Abiyata and Langano, the second Lake Awassa and the third lakes Abaya, Chamo and Chew Bahir. The Meki and Ziway Rivers feed Lake Ziway and, in turn, lake Abiyata. In the southern Abaya-Chamo sub-basin the principal surface water resources are the Bilate, Gelana, Gidabo and Sagan rivers.

Water uses in the Rift valley river basin

The widespread occurrence of saline and alkaline springs affects the quality of much of the surface waters of the basin, representing a major constraint to the accessibility of water resources in the basin, either for irrigation or for domestic or industrial water supply. Lakes Langano, Abiyata and Shala are highly mineralised and unusable. Lake Awasa itself is not used for either irrigation or water supply. Lake Ziway and the small Shalo Lake, near Lake Awasa, are the only lake sources where water quality is suitable for irrigation. With some exceptions, therefore, the lakes are not usable water resources, except for their important ecological functions and their tourism potential.

Meki and Ziway rivers have been developed for their water resources, mainly for irrigation. There are ongoing studies of irrigation schemes in the south, on the Gidabo, Galana and Bilate rivers which flow into Lake Abaya, and others.

Besides, some of the lakes in the basin are well utilized for recreational purposes. Ziway, Langano, Abaya and Chamo lakes are frequently used for recreational purposes. Langano Lake in particular is well developed for the purpose and is extensively used by the public. Abiyata Lake on the other hand is used extensively for mining Sodium Carbonate (Trona) from its saline waters.

The Genale – Dawa river basin

Location and size of the basin

The Genale-Dawa river basin is the largest basin of the country. It is situated in the southern part of Ethiopia between latitudes $3^0$30’N and $7^0$20’N and longitudes $37^0$05’E and $43^0$20’E. The basin covers an area of 172,889km^2.The river basin is bordered by the Wabi Shebelle basin on the north east, Rift valley river basin on the North West and by Kenya and Somalia to the south. The basin includes three regional states; namely Oromia, Somali and a small part of SNNPR.

Meteorological and Hydrological conditions

The major drainage systems defined by the three principal rivers: Genale, Dawa and Weyb, and their respective sub catchments. Tributaries of the centrally located Genale river originates from the southern flanks of the Bale mountains, and from the Sidamo mountains in the north west.

The Dawa river head waters are located in the Sidamo Mountains, while the Weyib river originates from the northern flanks of the Bale mountains. The Genale – Dawa Rivers and tributaries flow in deep valleys until reaching flatter and broader areas along their respective flood plains below an elevation of 400m. In contrast, the Weyib River flows mostly in a wide valley with intermittent deeply incised reaches along its course. A short distance upstream of the confluence of Genale and Dawa rivers, the Weyib converges with Genale near to the Somalia border at Dolo Odo. After this point, the combined water course becomes the Juba River which flows through Somalia to the Indian Ocean.

The mean annual rainfall of the basin is about 528mm/year with two main rainfall regime.

Land use, population and environmental conditions of the Rift valley river basin.

The total population in the Genale -Dawa basin is estimated to be 4.48m with 89% of it settling in rural areas and the remaining 11% in urban settlements. Rural settlements are relatively dense in the upper part of the basin and highly scattered in low land areas. With regard to urban settlements, towns are mainly concentrated in highland and mid highland of the basins. The distribution of land cover classes is predominated by grass land and bush land within the basin. These land cover types are found mainly in the hotter and dryer lowland areas. Cultivated land accounts for about 16% of the basin area. Cultivated lands fall mainly in the highland and mid-altitude areas. A substantial area (66%) within the basin is under grassland and bush land thereby providing a vital resource for a large livestock population. Compared to the rest of Ethiopia, there is still a significant proportion (7.8%) of forest and woodland in the basin.

The major farming systems prevailing in the basin are mixed agriculture, agro-silvo pastoral, agro-pastoral, pastoral and silvo-pastoral. The mixed agricultural system comprises state farms, private mechanized farms, and intensively cultivated small holder farms. Irrigated agriculture in the basin is mainly restricted to small scale irrigation and water harvesting activities in the Bale, Afder, Liben and Borena zones. In Somali region, there are a number of small scale irrigation schemes located along the Genale, Dawa and Weyib rivers. These schemes irrigated a narrow strip of land on the river banks. The irrigation potential in the basin has been estimated by the MoWR at some 1.07 million hectares.

1.3.2 Groundwater

Ethiopia consists of a large variety of metamorphic, sedimentary and igneous rocks. In a generalized summary (Figure 5 Simplified Geological map of Ethiopia), the extent of coverage of the different rock groups may be presented as follows:

- Precambrian basement complex = 18%
- Paleozoic and Mesozoic sedimentary rocks = 25%
- Tertiary volcanic rocks = 40%
- Quaternary sediments and volcanic rocks =17%

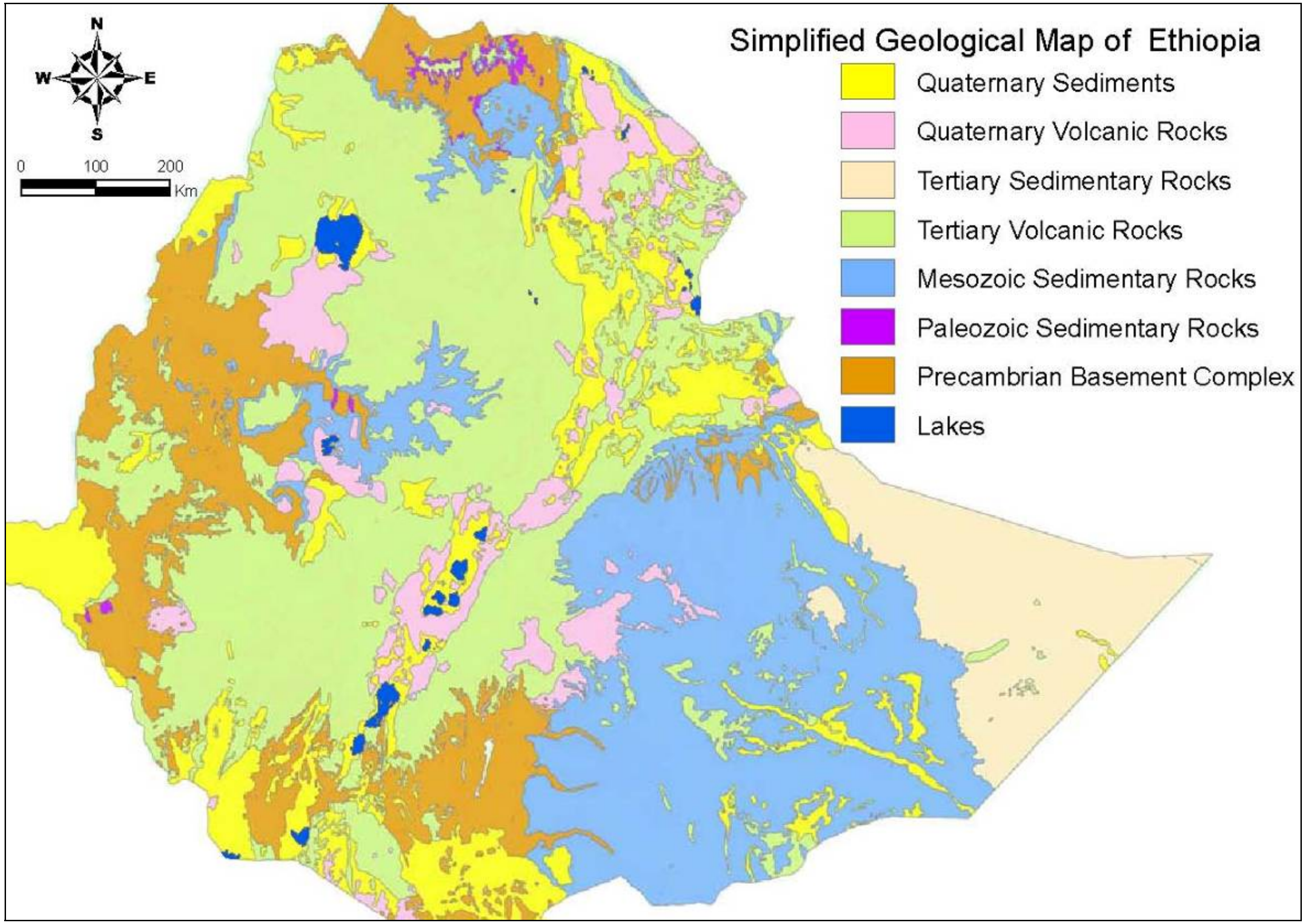


Figure 5 Simplified Geological map of Ethiopia

PRECAMBRIAN ROCKS

These rocks consist of granites, granodiorite, gabbro, gneiss, migmatites, granulites, amphibolites, schists, phyllites, etc. Precambrian rocks area exposed (Figure 5 Simplified Geological map of Ethiopia), in lowlands. The Precambrian rocks can be categorized in three complexes:

- The lower complex consists of various high-grade metamorphic rocks such as gneisses and banded migmatite;
- The middle complex consists of various moderate to high grade meta-sediments;
- The upper complex consists of thick succession of slightly metamorphosed sedimentary and volcanic rocks;

Generally, the basement crystalline aquifers occur in the weathered residual overburden (regolith) and fractured bedrocks. The aquifers are phreatic in character but may respond to localized abstraction in semi-confined condition. These rocks have very low fracture permeability and contain shallow groundwater where the yield varies between 1 and 5 l/s.

PALEOZOIC AND MESOZOIC SEDIMENTARY ROCKS

The Mesozoic sediments of Ethiopia occur mainly in three areas: the Ogaden basin, Mekelle outlier and Abbay basin (Figure 5 Simplified Geological map of Ethiopia). The general stratigraphy in the Ogaden basin is:

- Lower sandstone /Adgirat sandstone
- Hamanley limestone
- Urandab formation-Shales
- Kebridar formation-limestone
- Gypsum formation
- Upper sandstone

Carbonate rocks are among the most productive aquifers of the Mesozoic formations, even though their permeability and porosity vary considerably. Limestone formations rank among the best aquifers due to secondary porosity. Shales are unproductive but store small amount of water.

The Paleozoic formations are localized in the Ogaden and Tigray regions (Figure 7 Hydro geologic cross section (showing groundwater circulation)).Since Palaeozoic sediments are known to overlie impervious basement rocks, they can have good capacity to store water particularly in the channel fills and within the clastic sediment horizons.

Generally, Palaeozoic and Mesozoic sedimentary rocks are rich in groundwater where they receive highland recharge. Karsification is common structure in the limestones of eastern plateau and contain appreciable amount of water.

2.1.3. TERTIARY AND QUATERNARY VOLCANIC ROCKS

The most extensive groups of volcanic rocks are the Trap Series, erupted from fissures during the early and middle Tertiary. The Plio-Quaternary volcanics are largely restricted in the Rift valley. Substantial shield volcanoes consisting mainly of basalt lava developed on the Ethiopian plateau during the Miocene and Pliocene (Kazmin,1975).

The productivity of the Trap Series volcanics considerably varies from place to place. The yield is extremely high in some localities due to high degree of fracturing and the presence buried channels.

The yield of Quaternary volcanic rocks in northern Ethiopia varies considerably. A wide range of values exists in these rocks in the rift valley. They are also characterized by a series of fault control high discharge springs in the rift and adjacent escarpments.

The volcanic terrain of Ethiopia is characterized by the occurrence of numerous and different yield springs with a yield varied between 2 l/s in dry areas to 250 l/s .The yield of the springs is directly controlled by the rainfall cumul and presence of permeable hydrostructure.

In the rift valley, the potential aquifers are highly fractured and jointed basalts and ignimbrites. The weathered tuffs and paleosols are impermeable layers inhibiting vertical movement of groundwater, thus forming perched water bodies locally.

Permeable alluvial and colluvial deposits associated with lacustrine soils form local shallow aquifers in the rift floor and along major river valleys.

Quaternary Sediments

Quaternary sediments are found in the rift valley and along lower reach of major river courses (Figure 7 Hydro geologic cross section (showing groundwater circulation)). In the alluvial plains, alternating layers of fine and coarse sediments occur and in many cases; lacustrine sediments could be found beneath.

The alluvial sediments have moderate to high permeability. Those at the foot of the rift escarpment have relatively coarse sediments of moderate to high permeability and productivity. On the other hand, those plains in the lower rift floor have relatively finer grained sediments with moderate permeability and productivity. The vast plains of Baro,Akobo and Omo rivers have also moderate productivity.

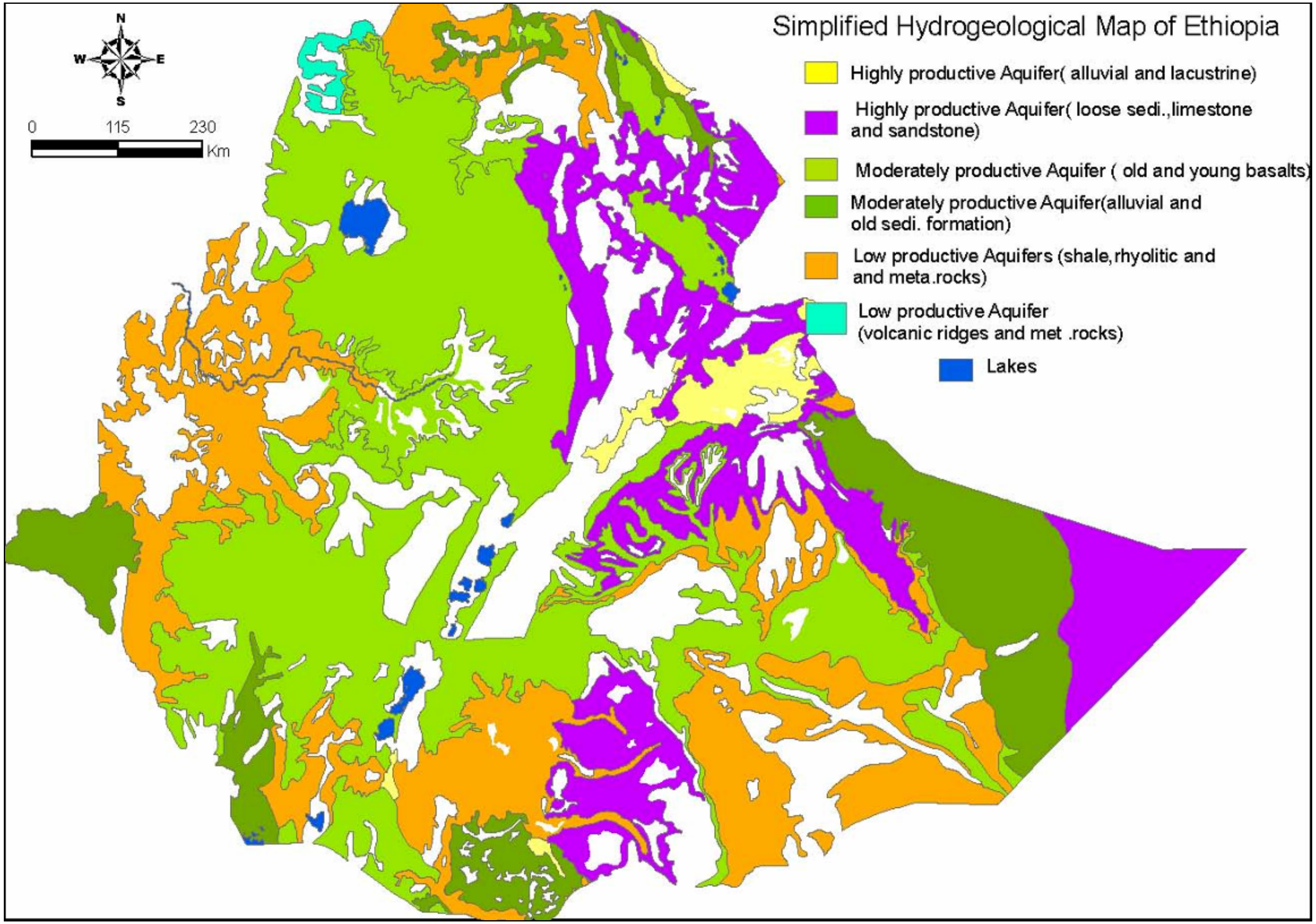


Figure 6 Simplified hydrogeological map of Ethiopia

GLOBAL VISION ON THE GROUNDWATER QUALITIES

The chemistry of groundwater is controlled by natural and anthropogenic process:

- Geomorphological geographical conditions,
- Climate,
- Geology and lithology of water bearing,
- Relation with surface water,
- Urbanization,
- Agriculture;

Critical natural water quality problems in Ethiopia are:

- High fluoride content in the rift (lakes region), ranging from 2 to 300 mg/L,
- High salinity in Afar depression and Ogaden basin. The highest ever recorded TDS in Ogaden is 10.000 ppm,
- High iron content in the rift (Yirgalem-Yirgachefe areas).

The Ethiopian rift is characterized by high salinity (TDS) due to high degree of water-rock interaction, evaporation and the discharge of thermal water.

Most waters in the volcanic highlands have well to excellent chemical quality while waters in rift valley are characterized by high Na, HCO3 and F contents.

Generally, the salinity increases from highlands to the lowlands. It increases from region of high rainfall and lower evaporation to regions of lower rainfall and higher evapotranspiration. Due to intensive evaporation and continuous input of mineralized hot springs, some rift lakes have an high salinity with the TDS value from 20 to 40 g/L.

POLLUTION

Face to a poor environmental awareness, people use rivers and lakes as waste water discharge, and then deteriorate the quality of water. The excessive anthropogenic discharge is common in urban areas.

Since pit latrines and domestic waste discharge mechanism are common all over the country, the risk to contaminate groundwater is very important. The pollution is finally quite common in rivers and shallows springs closed to urban areas, and then groundwater pollutions (bacteria and nitrates) increase slowly but durably. Some inorganic pollutants such as barium, antimony, lead and silver are reported in Addis Ababa area.

As mentioned here before, the rift valley waters are characterized by high fluoride concentration with wide range from 2 mg/L from 10 mg/L for cold groundwater. Consumption of high fluoride water in Ethiopian rift causes severe health problem to over 10 millions of persons.

The most likely source of F is micas, amphiboles and pyroxene, which contain appreciable amount of F by OH substitution. Most of F fluoride comes from acidic volcanic rock such as pumice, obsidian, pyroclastic deposits, ignimbrite and rhyolite. As pumice fall deposits are widespread in Ethiopian rift valley: these rocks represent the first potential of fluoride. Face to a high fluoride content, deep groundwaters in acidic volcanic aquifer are not suitable for drinking water supply. Note that groundwaters in the basaltic aquifers are known to have low concentration of fluoride.

In Ethiopia the groundwater pollution is fortunately low, but the development of the population; industry and agriculture threaten this favorable situation and justify the installation of a hydrogeological network for survey.

Globally, the major water quality problems concern:

- High Fluoride in the rift valley,
- High salinity in rift valley and the Ogaden basin,
- Hard water in sedimentary aquifers,
- Radioactivity in the rift valley aquifers,
- High Iron content in some groundwater of the rift valley,
- Local pollution from urban and industrial effluents.

HYDROGEOLOGY

Ground waters are stocked in pore spaces of sediments (sand, gravels, and sandstone) or in fissures of fractured rock, like crystalline rock, limestone and basalt. The regional volume of saturated rock makes an aquifer, where water is flowing from a recharge zone to outputs such as springs, rivers, lakes, evaporation area, wells, well field….

First statement, the water velocity inside an aquifer, can't be compared to surface water, as it varies from one meter to few ten meters per year, face to one (or more) meter per second for a river.

An aquifer is characterized by porosity and permeability:

- Porosity is the ratio of pore volume to the total volume of the media.
- Permeability is the capacity of water to be transmitted (flow) in the media.

In terms of the quality of groundwater, the "confined" or "unconfined" characters of an aquifer are essential as shown in Figure 7 Hydro geologic cross section (showing groundwater circulation).

- A confined aquifer is overlain by an impermeable layer that prevents recharge and contamination by infiltration of rainfall or surface water.
- In an unconfined aquifer, the permeable rock outcrops, and recharge and contamination are possible.

These sectors are thus the sensitive zones of the aquifers. It should be noticed that confined area can also be concerned by a deterioration of the water quality due to groundwater flow.

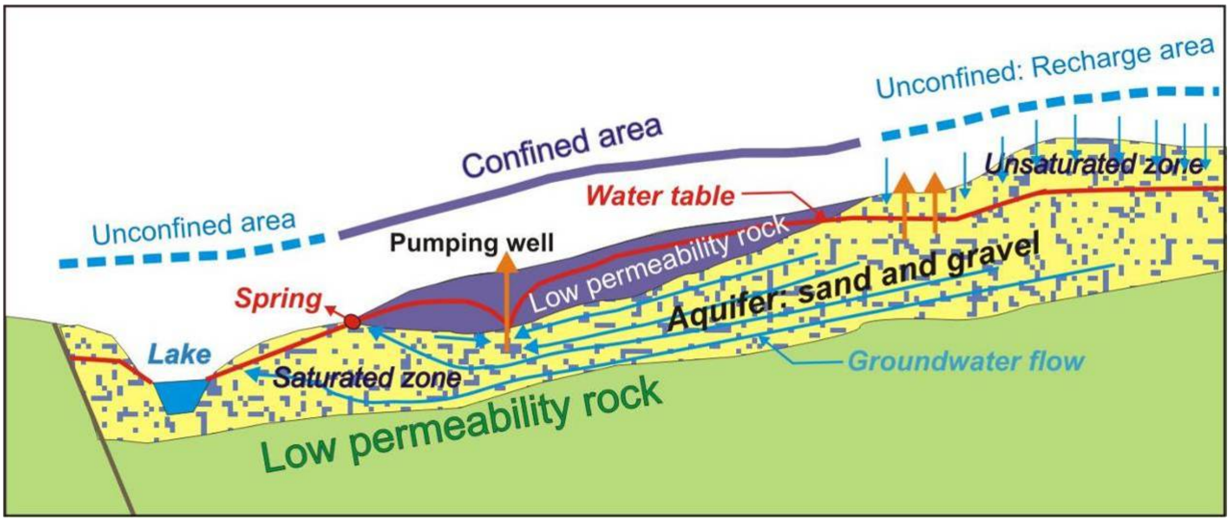


Figure 7 Hydro geologic cross section (showing groundwater circulation)

WATER QUALITY DETERIORATION

Industrialization, urban development, intensive agriculture, increases the pollution stress on the aquatic environment. River, lakes, oceans are now considered as a convenient receiver for waste water. But, interactions between groundwater and surface water are complex. Consequently, groundwater pollution, sometimes referred to as groundwater contamination, is not as easily classified as surface water pollution.

Water uses	Consuming	Contaminating
Domestic use	Yes	Yes
Animal breeding	Yes	Yes
Irrigation	Yes	Yes
Forestry and logging	No	Yes
Food processing	Yes	Yes
Industry	Yes	Yes
Mining	Yes	Yes
Hydroelectric power	No	No
Transport	No	Yes

Table 1 Activities with impact on water quality

By their nature, the groundwater aquifers are sensitive to contamination from sources that should not be directly affected surface water bodies, and the distinction of point (non point source) should be irrelevant. A spill of a chemical contaminant on soil, located away from a surface water body, can not necessarily create a point source or non-point source pollution, but nonetheless can contaminate the aquifer below.

Then, analysis of groundwater contamination must focus on Geological conditions (confined or unconfined aquifer), soil characteristics and hydrology, as well as the nature of the contaminant itself, such as:

Source of pollution	Quality control
Organic waste water issued from sewage network, or food-manufacturing.	Complex microbiological analyses are then necessary to detect potential presence of faecal pollutions,
Agriculture and irrigation outlets can produce pollution by fertilizers, pesticides and herbicides	Quality control will be based on phosphate, potassium measurement
Industrial effluents can produce toxic chemical organic or inorganic pollutions	Quality control will be based on measurement of total hydrocarbons and chlorinated hydrocarbons.

Geologic environment can also have an impact on water composition. Salt or gypsum rocks can produce high concentration in chloride or sulphate. In Ethiopia we have to keep in mind, fluoride produced by the interaction between water and some volcanic rocks, iron in high concentrations in Awassa – Yirgachefe area, potassium in Butajira-Asela areas, Chloride in Afdera and Dallol areas, and Sulphate in Ogaden basin.

2. Water monitoring purposes

In the preamble, we propose to make a chapter introduction on water monitoring to give explanation on the proposed guidelines.

2.1 Monitoring program types

Freshwater is a finite resource, essential for agriculture, industry and even human existence. Without freshwater of adequate quantity and quality, sustainable development will not be possible.

But the extent of the human activities that influence the environment has increased dramatically during the past few decades; terrestrial ecosystems, freshwater and marine environments and the atmosphere are all affected. The scale of socio-economic activities, urbanization, industrial operations and agricultural production, has reached the point where, in addition to interfering with natural processes within the same watershed, they also have a world-wide impact on water resources. As a result, very complex inter-relationships between socio-economic factors and natural hydrological and ecological conditions have developed.

A pressing need has emerged for comprehensive and accurate assessments of trends in water quantity and quality, in order to raise awareness of the urgent need to address the consequences of present and future threats of contamination and to provide a basis for action at all levels. Reliable monitoring data are the indispensable basis for such assessments

Monitoring is defined by the International Organization for Standardization (ISO) as: "the programmed process of sampling, measurement and subsequent recording or signaling, or both, of various water characteristics, often with the aim of assessing conformity to specified objectives". This general definition can be differentiated into three types of monitoring activities that distinguish between long-term, short-term and continuous monitoring programs as follows:

- Monitoring is the long-term, standardized measurement and observation of the aquatic environment in order to define status and trends;
- Surveys are finite duration, intensive programs to measure and observe the quantity and the quality of the aquatic environment for a specific purpose;
- Surveillance is continuous, specific measurement and observation for the purpose of water quality management and operational activities;

It is important to note the emphasis given to collection of data for a purpose in the definitions of water quality and quantity monitoring above.

This purpose is most commonly related to water quality and quantity management, which aims to control the physical, chemical and biological characteristics of water. Elements of management may include control of pollution, use and abstraction of water, and land use. Specific management activities are determined by natural water quantity and quality, the uses of water in natural and socio-economic systems and prospects for the future.

Based on our interpretation of the Terms of reference, we have considered that the project will be close to a surveillance network implementation.

2.2 Water bodies concerned

Different types of water bodies must be concerned by the project, as all major freshwater resources are subject to anthropogenic influences or intentionally used for municipal or industrial supply, irrigation, recreation or other purposes. For these, water quantity and quality assessment techniques of the following types of water resources will be taken into consideration:

- Rivers and streams of all sizes ;
- Lakes of all sizes and types;
- Reservoirs of various types, especially river impoundments.
- Ground waters of various types, shallow or deep, and phreatic or confined.

All are inter-connected by the hydrological cycle with many intermediate water bodies, both natural and artificial.

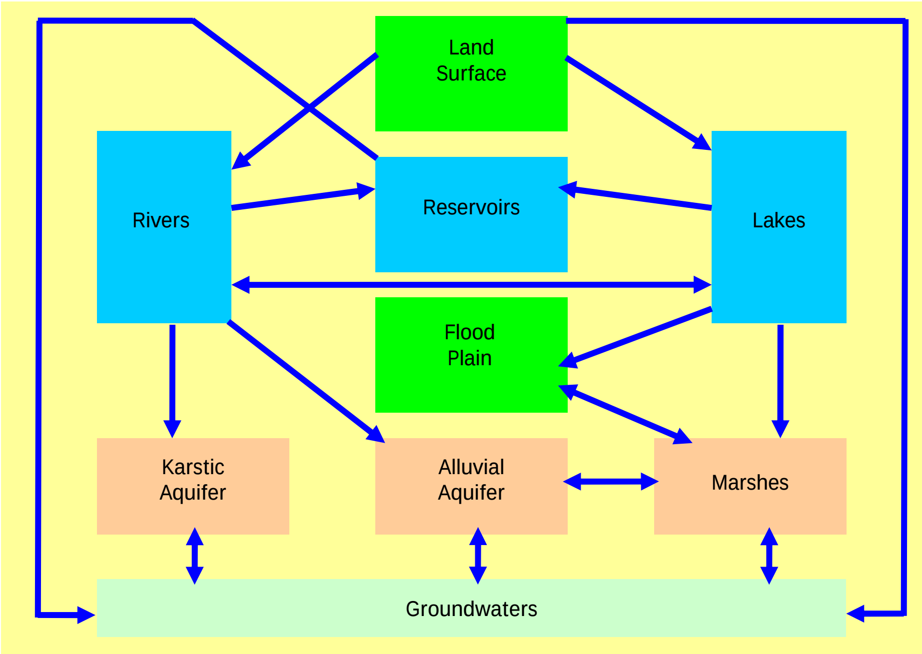


Figure 8 Inter connections between fresh water bodies

So, it is essential that all available hydrological data must be included in a water quantity and quality assessment as water is profoundly affected by the hydrology of a water body.

Based on our interpretation of the Terms of reference, we have considered that the project will include all water bodies and saline resources.

2.3 SPATIAL AND TEMPORAL VARIATIONS

If the minimum information required should be the seasonal variation in river discharge, the thermal and mixing regimes of lakes, and the recharge regime and underground flow pattern of ground waters, detailed information's are required when quality problems occur. So, the frequency of the measurement is closely linked to the water residence time in the concerned water body.

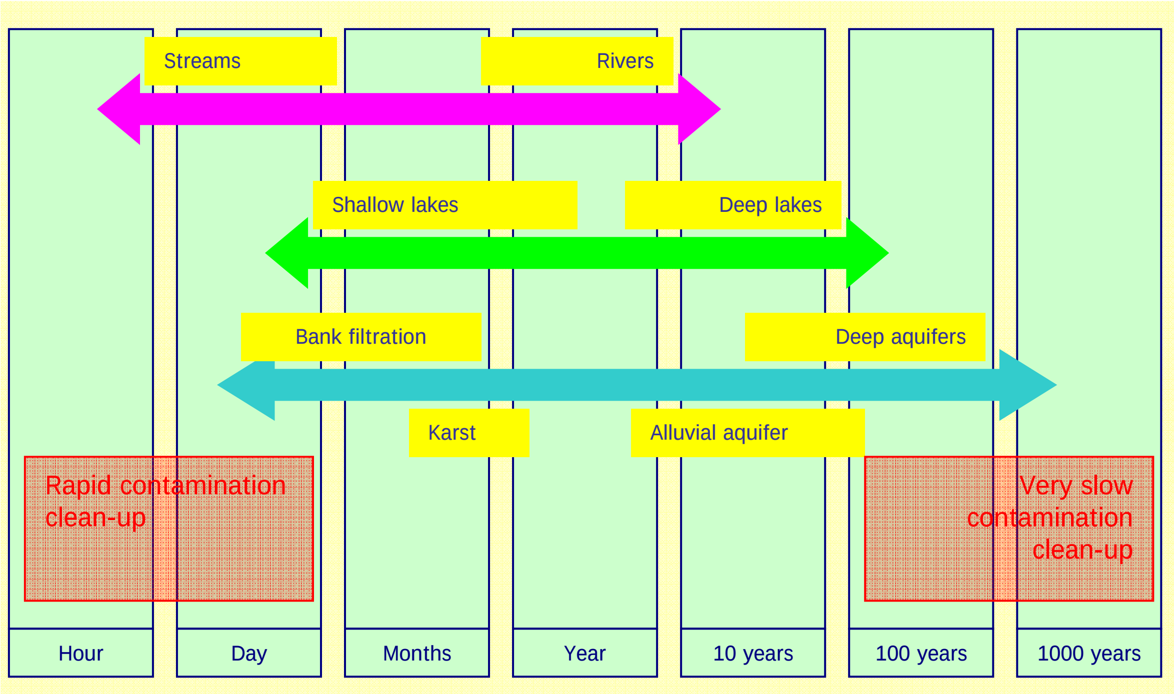


Figure 9 Typical water residence times in inland water bodies

The common ranges of water residence time for various types of water body are shown in "Figure 9 Typical water residence times in inland water bodies". The theoretical residence time for a lake is the total volume of the lake divided by the total outflow rate (V/ΣQ).

Residence time is an important concept for water pollution studies because it is associated with the time taken for recovery from a pollution incident. For example, a short residence time (as in a river) aids recovery of the aquatic system from a pollution input by rapid dispersion and transport of waterborne pollutants.

Long residence times, such as occur in deep lakes and aquifers, often result in very slow recovery from a pollution input because transport of waterborne pollutants away from the source can take years or even decades. Pollutants stored in sediments take a long time to be removed from the aquatic system, even when the water residence time of the water body is short.

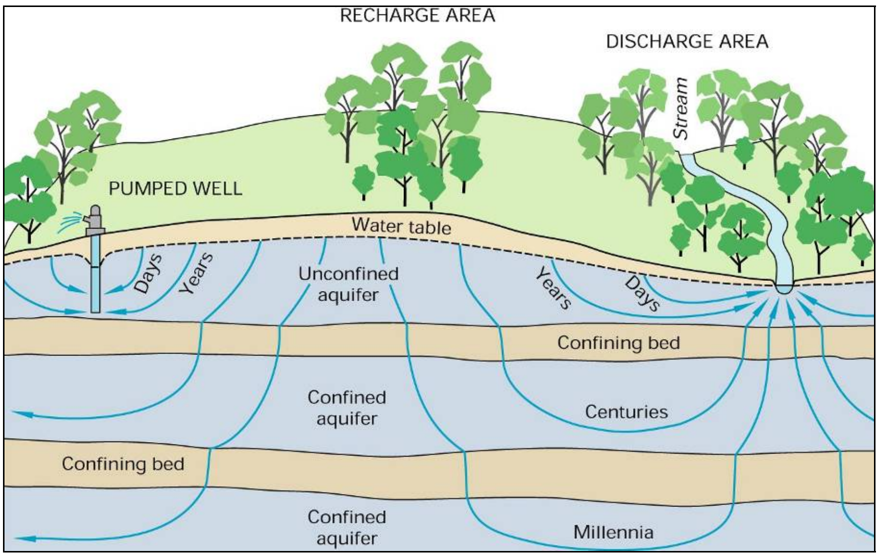


Figure 10 Scale of time

As spatial variation in water quality is one of the main features of different types of water bodies, and is largely determined by the hydrodynamic characteristics of the water body. Water quality varies in all three dimensions which are further modified by flow direction, discharge and time.

Then, hydrodynamic properties of water bodies must be known to build an effective water quality monitoring system. Interpretations of water quality data can not be done efficiently without any knowledge relative to the temporal and spatial variability of the hydrological regime. Consequently, water quality can not usually be measured in only one location within a water body but may require a grid or network of sampling sites, linked to hydrological stations.

2.4 MONITORING OBJECTIVES

Since water resources are usually put to several competing beneficial uses, monitoring which is used to acquire necessary information should reflect the data needs of the various users involved.

Consequently, there are two different types of monitoring programs, depending on how many assessment objectives have to be met:

- Single-objective monitoring which may be set up to address one problem area only. This involves a simple set of variables for a dedicated purpose, such as flood management;
- Multi-objective monitoring which may cover various water uses and provide data for more than one assessment program, such as drinking water supply, industrial manufacturing, fisheries or aquatic life, thereby involving a large set of variables.

The process of determining objectives should start with an in-depth investigation of all factors and activities which make influence, directly or indirectly, on water quality and quantity. Inventories have to be prepared on:

- the geographical features of the area, including: topography, relief, lithology, pedology, climate, land-use, hydrogeology, hydrology etc.,
- water uses, including: dams, canals, water withdrawal for cities and industries, agricultural activities, navigation, recreation, fisheries, etc., and
- pollution sources (present and expected), including: domestic, industrial and agricultural, as well as their stage of pollution control and waste treatment facilities.

N°	Type of operation	Major focus of water quality (and quantity) assessment
		Common operations
1	Multipurpose monitoring	Space and time distribution of water quality and quantity in general
2	Trend monitoring	Long term evolution of quality (pollution …)
3	Basic survey	Identification and location of major survey problems and their spatial distribution
4	Operational surveillance	Water quality and quantity for specific uses
		Specific operations
5	Background monitoring	Background levels for studying natural processes; used as reference point for pollution and impact assessments
6	Preliminary surveys	Inventory of pollutants and their space and time variability prior to monitoring programme design
7	Emergency surveys	Rapid inventory and analysis of pollutants, rapid situation assessment following a catastrophic event
8	Impact surveys	Sampling limited in time and space, generally focusing on few variables, near pollution sources
9	Modelling surveys	Intensive water quality or quantity assessment limited in time and space and choice of variables
10	Early warning surveillance	At critical water use locations such as major flood alert, or drinking water abstractions or fisheries; continuous and sensitive measurements

Table 2 Typical objectives of water quality and quantity assessment operation

Based on our interpretation of the Terms of reference, we have considered that the primary role of the system will be to provide information to decision makers on the status (and trends) of water resources of Ethiopia, for economic and social development of the country. Such information will be required for:

Assessing water resources in quantity and in quality, distribution in time and space, evaluating the potential for water-related development, and the ability to supply actual or foreseeable demands;

Assessing the impacts on water resources of other non-water sector activities, such as urbanization or industry;

Providing security for people and property against water-related hazards, particularly floods and droughts.

Type of operation	Station density and location	Sampling or observation frequencies	Number of variables considered	Duration	Interpretation lag
Multi-purpose monitoring	medium	Medium (12 per year)	medium	Medium (> 5 years)	Medium (1 year)
Other common water quality operations					
Trend monitoring	low: major uses and international stations	***very high***	low for single objective; high for multiple objective	***> 10 years***	> 1 year
Basic survey	***high***	depending on media considered	medium to high	once per year to once every 4 years	1 year
Operational surveillance	low: at specific uses	medium	***specific***	variable	Short (month/week)
Specific water quality operations					
Background monitoring	***Low***	low	low to high	variable	medium
Preliminary surveys	high	usually low	low to medium (depending on objectives)	***short < 1 year***	short (months)
Emergency surveys	medium to high	high	***pollutant inventory***	very short (days-weeks	***very short (days)***
Impact surveys	limited downstream pollution sources	medium	***specific***	variable	short to medium
Modelling surveys	***specific (e.g. profiles)***	***specific***	***specific (e.g. O_2, BOD)***	short to, medium two periods: calibration and validation	short
Early warning surveillance	very limited	***continuous***	very limited	unlimited	instantaneous

Table 3 Typical characteristics' of water quality and quantity assessment operation

The levels (high, medium, low) of all operation characteristics (frequency, density, number of variables, duration, and interpretation lag) are given in relation to multi-purpose monitoring, which has been taken as a reference. Important monitoring characteristics are emphasized in bold.

- Background monitoring has usually been developed to help the interpretation of trend monitoring (time variations over a long period) and the definition of natural, spatial variations.

- Models and their related surveys have usually been set up to predict the water quality for management purposes prior to pollution treatment, or to test the impact of a new water pollution source, and are thus closely connected to operational surveillance and impact surveys.
- Early warning surveillance is undertaken for specific uses in the event of any sudden and unpredictable change in water quality, whereas emergency surveys of a catastrophic event should be followed in the medium and long-term by impact surveys.

For practical reasons, several types of regular monitoring are often combined. In fact, monitoring activities are also greatly dependent on the level of deterioration of the aquatic environment.

The fundamental question at this stage of the project is what forthcoming issues should be considered within basic monitoring which is routinely performed on all water bodies. Often, water quality degradation (linked to water quantity) becomes a major concern and early warning monitoring might have to be installed.

Based on our interpretation of the Terms of reference, we have considered that we were in this previous context.

2.5 MONITORING NETWORKS REVIEW PRINCIPLES

A monitoring network is based upon two considerations, namely:

- the monitoring objectives
- the physical characteristics of the systems to be monitored.

The identification of the monitoring objectives is the first step in the design and optimisation of monitoring systems. Related to this is the identification of the potential data users and their future needs. If there is more than one objective, priorities need to be set. Identification of monitoring objectives is also important because they determine the scale of changes to be detected in the data, the kind of information to be extracted from the data and therefore the way the data are analyzed.

The analysis of the data, obtained from the network, is also determined by the dynamics of the measured processes. The physical basis of the relevant processes must be known in order to be able to make preliminary guesses of the scale of the variability with respect to space and time.

To enable an optimal design of a monitoring network, a measure is required, which quantifies the effectiveness level. Which measure is adequate depends on the monitoring objectives. Often, this measure is related to statistical concepts like errors in areal estimates, interpolation error, trend detection, etc, and can be formulated as a function of:

- sampling **variables** (what),
- sampling **locations** (where),
- sampling **frequencies** (when), and
- sampling **accuracy** (with what (technique/equipment))

These quantities also determine the cost of establishing and running of the network, like the costs related to land acquisition, station construction, equipment procurement and installation, station operation, maintenance, data processing and storage and staffing of field stations and data centers. Once the relationship between the chosen effectiveness measure and costs have been established, the optimal network can be found, in principle, by weighting the two in a cost – effectiveness analysis. The optimization process is depicted in Figure 11 Network optimization process

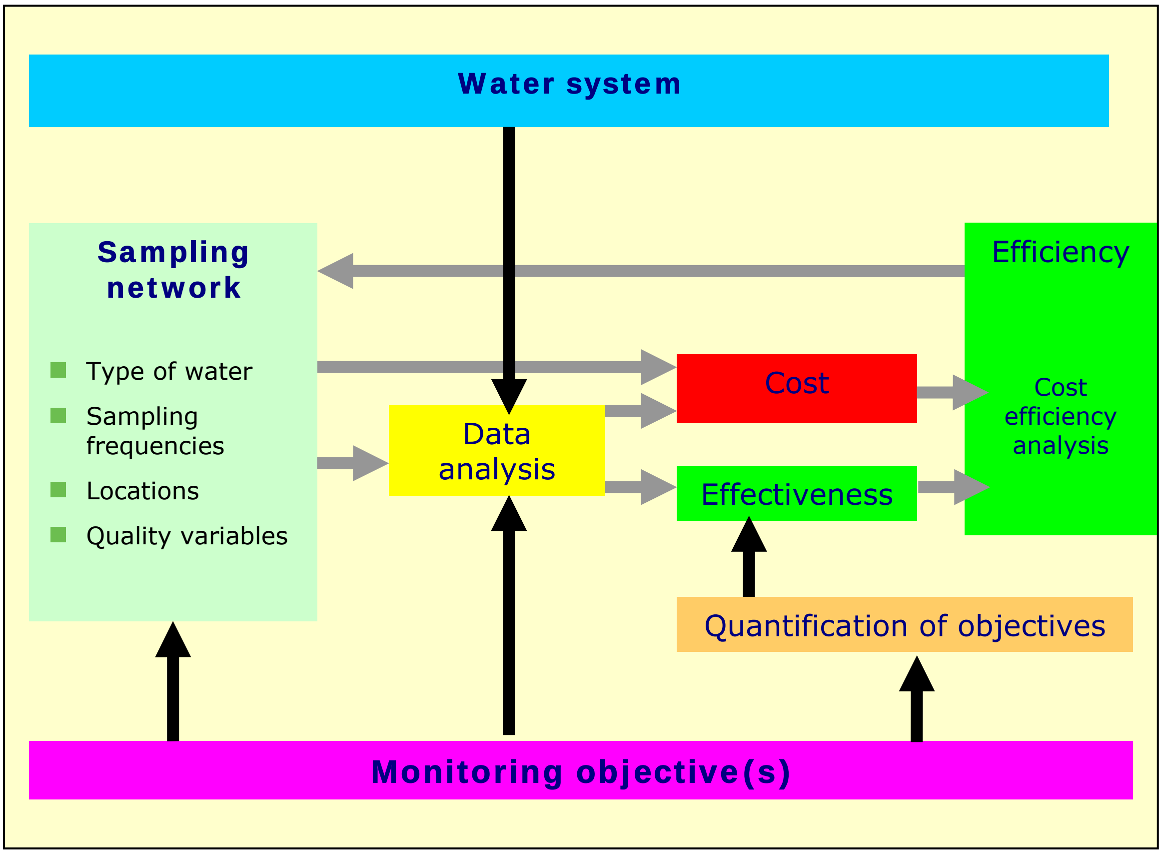


Figure 11 Network optimization process

It is stressed that once the network is operational, it has to be evaluated regularly to see whether (revised) objectives still match with the produced output in a cost-effective manner. A network, therefore, is to be seen as a **dynamic system** and should never be considered as a static entity. This requires some flexibility in establishing new stations and closing down others.

STEP IN NETWORK DESIGN

The sequence of steps to be carried out for network review and redesign include:

- 1. Institutional set-up: review of mandates, roles and aims of the organisations involved in the operation of the HIS. Where required communication links should be improved to ensure co-ordination/integration of data collection networks.
- 2. Data need identification: the existing and potential future data users have to be approached to review their data needs.
- 3. Objectives of the network: based on the outcome of step 2 a synthesis of Water Information Need must listed a set of objectives in terms of required network output. The consequences of not meeting the target are to be indicated.
- 4. Prioritisation: a priority ranking among the set of objectives is to be made in case of budget constraints.
- 5. Network density: based on the objectives the required network density is determined using an effectiveness measure, taking in view the spatial (and temporal) correlation structure of the variable(s).
- 6. Review existing network: the review covers existing network density versus the required one as worked out in step 5, spreading of the stations in conjunction with the hydrometric and groundwater network, available equipment and its adequacy for collecting the required information, and adequacy of operational procedures and possible improvements. Deficiencies have to be reported upon.

- 7. Site and equipment selection: if the existing network is inadequate to meet the information demands additional sites have to be selected as well as the appropriate equipment.
- 8. Cost estimation: costs involved in developing, operating and maintaining the existing and new sites as well as the data centres have to be estimated.
- 9. Cost-effectiveness analysis: cost and effectiveness are compared. The steps 5 to 8 have to be repeated in full or in part if the budget is insufficient to cover the anticipated costs.
- 10. Implementation: once the network design is approved the network is to be implemented in a planned manner where execution of civil works, equipment procurement and installation and staff recruitment and training is properly tuned to each other.
- 11. The network has to be reviewed after 3 years or at a shorter interval if new data needs do develop. The above listed procedure should then be executed again.

Based on this schedule, tasks 1 to 8 are part of the present document. As no budget limit has been defined, task n°9 has been done linked to task 8.

3. Review of the existing situation

3.1 INSTITUTIONAL CONTEXT

The totality of institutions involved in Water Resources Assessments (long or short term) and legislation and regulations governing by the activities of these institutions, constitutes the general administrative – legal framework of the Water Resources Assessments program which in fact the goal of the project. It is the result by the history of Ethiopia, the socio-economic context and it is the component of the institutional system which ensures the inventory, the development, the planning and the management of the natural water resources of the Country.

For this purpose, we have listed institutions:

- That require information's for water-resource planning;
- That collect data and process it to provide water resource information's;
- That have relationships between various institutions, corresponding to jurisdictions, stakeholders participation, public awareness, co-ordination and privatization;

Institutions	Relevant mandate	Real Activities	Facilities
Hydrology Dept. MoWR	Collect, process, analysis and disseminate hydrological information's	Collect, process and disseminate level and flow data rivers, lakes and reservoirs Collect, process and disseminate sediment and Water quality data of some parts Collect, process and disseminate GW water level data	Central and regional Offices, A small laboratory that run by the department and workshops
Water quality team in Water Administration and urban water supply Dept. MoWR	Control, monitor, and regulate the water quality of drinking water	Collect water quality analysis sample from all water supply schemes and analysis their quality Process the development of water quality map of the country (data collection for two regions completed and the others planned) Deliver trainings for regional bureaus Monitor Awash basin water quality at 8 stations	Central organized office, equipped laboratory at the ministry office
Hydro-geological team at Irrigation and drainage Dept. MoWR	undertake studies and prepare plans for utilization of water resources for Irrigation purpose	Evaluate the hydro-geological aspects of Irrigation and Draining projects Collect different phase project studies, which contain information's about GW	Central organized office in the ministry

Institutions	Relevant mandate	Real Activities	Facilities
		conditions of the project sites.	
Water works Enterprise	To do study, design, supervision and construction of different water works They give service for the ministry as contractor based	They collect water sample and analyze the water quality but not for their direct use or monitoring purpose rather for their client	Have laboratory that analyze water quality at the ministry
Geological Survey of Ethiopia	The main objectives of the geological survey are to prospect, explore, delineate and estimate ore deposits, groundwater resources, thereby accelerating economic growth of the country	Regional geological mapping at the 1:250,000 scales has covered a third of the country, mostly in Precambrian areas. Hydrogeological mapping of about 35% of the country has also been carried out at various scales out of which 13% is at (1:250,000). supplies various technical services to outside users, mainly with regard to industrial mineral and construction material studies, coal and groundwater exploration, engineering geology studies and ground geophysical surveys	well equipped laboratory that analyze water quality in Addis Ababa
Awash River Basin Authorities	Administer the water resources of Awash river	Allocate the amount of water released for different users Monitor the quality of water in 8 stations Collect water charges from respective users	Have Laboratory that analyse Water Quality ((they use the laboratory that mentioned under the facility of water works enterprise)
National Meteorological Agency	*collecting, analyzing and studying the atmosphere, provide weather forecast and early warnings on the adverse effects of weather and climate of Ethiopia*	Collect meteorological data from 700 stations in all over the country. Distribute process or semi-process data for different users Forecast weather and announced to the public Support different research work and release booklets in regular manner.	Offices and personnel for most of the station point Radio data transmission system for key stations
Ministry of health	Responsible for carrying out drinking water-quality monitoring and surveillance, according to	Prepare hygiene and environmental health	The MOH does not run its own water-quality laboratory, but relies on laboratory

Institutions	Relevant mandate	Real Activities	Facilities
	Public Health Proclamation No. 200/2000. The Department of Hygiene and Environmental Health is in charge of developing policy guidelines on water-quality surveillance. Ensure measures for the control of water & food quality and prevention of accidents, injuries & environmental pollution	regulations and guidelines carry out drinking water-quality surveillance	facilities at the Ethiopian Health and Nutrition Research Institute (EHNRI).
Federal Environment Protection authority	propose incentives or disincentives to discourage practices that may hamper the sustainable use of natural resources or the prevention of environmental degradation or pollution; The Authority formulate practicable environmental standards based on scientific and environmental principles. ensure compliance with those standards;	conduct water quality monitoring of Awash river at 22 stations	have a laboratory jointly with Addis Ababa EPA
Regional water bureaus	Are responsible for providing safe water, which involves planning, developing, constructing and managing the water supplies.	they check approximately 5−10% of point sources annually	Most are equipped with laboratories (e.g. SNNPR, Oromia, Amhara)
Addis Ababa Water and Sewerage Authority	*Provide adequate and clean drinking water supply for the capital city.* *Collect,* treat and dispose sewage from the city	Conduct quality monitoring of the drinking water supply to Addis Ababa city regularly Conduct quality control on sewage treatment process	Have its own water quality and sewage control laboratory.
Universities(Bahirdar, Arbaminch)	Have no specific mandates in relation to water quality monitoring.	Conduct research and studies in different fields including water quality monitoring of surface waters.(e.g lake Abaya and chamo, and lake Tana)	They have teaching and research laboratories
Universities		Addis Ababa University:	

Table 4 Institutions involved in Water Resources

3.2 SURFACE WATER NETWORK

The currently has the responsibility to collect, process (and store), analyze and use/apply data and information on the quantity and quality in space and time of the country's water resources nationwide.

Given the size of the country and the magnitude and complexity of its water resources, the Federal Democratic Republic of Ethiopia through its Hydrology Department in the Ministry of Water Resources operates around 560 gauging stations in 12 river basins of which 454 are at present operational throughout the country. Basin-wide classification of these stations is given in "Table 5 Number of gauging stations".

Almost all of these are "water level recording station" and at most observations are carried out manually twice a day. Continuous measurement (using automatic recorders) is gradually being (re-) introduced on 95 stations with an Automatic Water Level Recorder using a chart recorder, and 8 stations are equipped with Radar Sensor.

	Branch office	Nb of stations
1	Addis Ababa (Centeral)	108
2	Assosa	31
3	Awash	37
4	Awassa	93
5	Bahirdar	43
6	Debere Markos	38
7	Jimma	39
8	Kombolcha	40
9	Mekele	44
	Total	473

Table 5 Number of gauging stations

3.2.1 Review of the existing surface water network

DATA ACQUISITION

Water level data are collected at 412 operational gauging stations. All stations are equipped with a Staff Gage that is controlled by an observer twice a day and the data are noticed in a Stage Height book. Some other stations (95) are equipped with an Automatic Water Level Recorder using a chart recorder, and 8 stations are equipped with automatic logger and radar Sensor, but they have some troubles.

Hydrology Department has 13 current meters (12 in Regional offices and one on Head office) and one ADCP. Current metering is usually implemented at low and medium flows.

The high flows are too difficult to manage. The ADCP has been implemented but it doesn't work for flood flows because of sediment density. It can be used only for low or medium flows.

DATA PROCESS AND DATA ANALYSIS

Data processing of surface water is largely based on the use of a specialized hydrological data processing software package known as HYDATA. This program can be used to check quality of data (through various statistical and other analyses), fill gaps (through regression analysis and use of time series), generate statistics, calculate rating equations, and convert water level data into discharges and volumes and all the usually required hydrological data manipulations.

The Hydrology Department Data Processing Team has been operating a GIS for 5 or 6 years. Details on the locations of operating stations, proposed new stations and those recommended for rehabilitation are on the system. The system runs on ARCVIEW.

The work of the Data processing Team is greatly slowed by the fact that almost all data collected in the field are manually collected (Observation of gage Height book) or in some cases using old-fashioned chart recorders (AWLR). Station modernization would greatly increase the productivity of the Data processing Team and free up time for activities such as digitizing the backlog of data on charts and to make greater use of the GIS.

FLOOD FORECAST

A flood forecast system allows ruling the dams during crisis periods. Hydrology Department hourly provides data concerning the water levels progress to the dam handlers. The water levels are provided par observers of gage height hourly, by phone to Head office hydrology Department. The Head office transmits the information by Radio to the Dams managers.

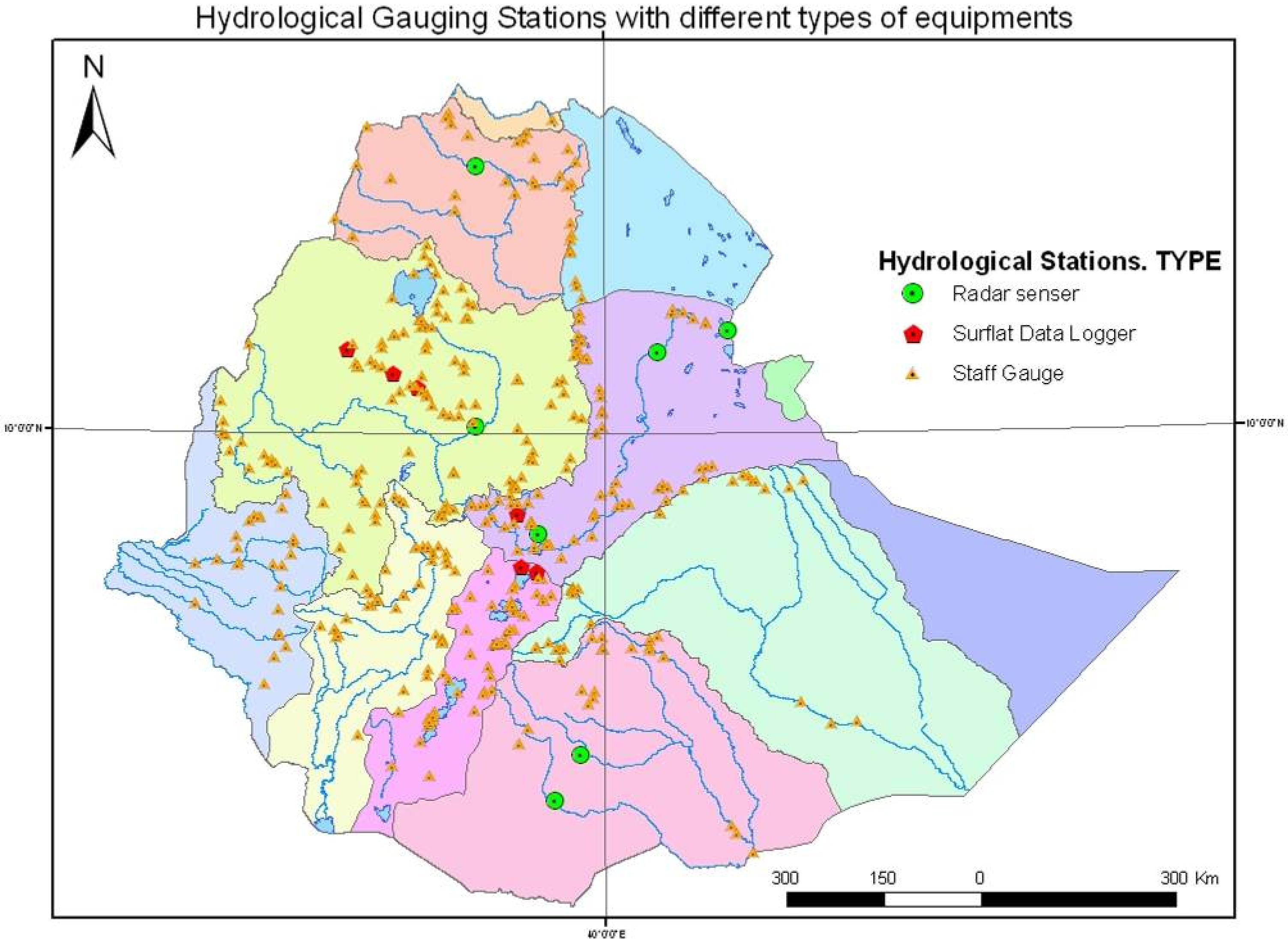


Figure 12 Gauging stations location

3.2.2 Major difficulties

The study made on Tana Beles basins by SMEC in 2008 gives a good basis for assessing the different type of problems encountered.

- Location of measuring sites: because of accessibility, most hydrometric stations are located along or near the main roads. Considering the limited number of all-weather roads in the country, this choice is understandable. However, from a hydrometric point of view the locations are certainly not always optimal with respect to:
  - ✓ stable and regular cross section (i.e. not affected by local scour or sedimentation)
  - ✓ straight uniform reach of the river channel
  - ✓ good sensitivity (readable changes in stage at small changes in discharge)
  - ✓ no excessive turbulence and eddies
  - ✓ no overflow of banks
  - ✓ no excessive vegetal growth
- Siltation: almost all rivers carry heavy sediment loads at high river stages and in the lower stretches of these rivers sedimentation is often quite severe. SMEC observed that the river bed rose more than 1.5m near Addis Zemin between 1990 and 2002. Siltation could affect a larger number of stations, especially when the gauging site is in the lowlands of the basins. If sediment is not removed by the observer, staff gauge segments appear not readable or it can only for hight water level (wet season). Because of sedimentation problems the rating curves obviously have to be regularly updated by current meterings. The low human power can't permit to make current meterings as requested.
- Bank overflow: SMEC could see during their field visits that the carrying capacity of the Ribb River, near Addis Zemen became less over time, the river banks regularly overflows. The establishment of rating curves is difficult as long as there are overflows.
- Unstable cross sections: The rating curve may show a gradual shift in time due to sedimentation. But also, some stations may see the cross section suddenly change after a flash flood due to scour of the river banks, for example.
- Lack of discharge measurements at high river stages: As it was said by Hydrology Department and observed by SMEC, a very serious problem at almost stations is that hardly any current meterings took place during peak floods, even though this would be possible where BOC's are available. As a result rating curves are usually extrapolated beyond reasonable limits. Because of this, the data analysis is impossible: average annual runoff, simple hydrological characteristics… Discharges outside the range of the current meterings are estimated based on extrapolated rating curve formulae.
- Condition of station equipment: All staff gauges should be in reasonable good condition. The Tech Support team can build and repair easily. But, Branch office staffs are not enough to visit, repair and maintain all stations when necessary.
- Condition of equipment for current metering and sediment sampling: The equipment available for the current meterings and the sediment sampling should be in good condition. The following equipment is available:
  - ✓ Wading rod and equipment to measure from bridge, built by tech support team
  - ✓ 13 current meters: One for each crew (12) and one for the head office
  - ✓ Different Weights
  - ✓ Sediment samplers
  - ✓ Miscellaneous: cables, etc.

But, there are no facilities available in Ethiopia to regularly re-calibrate the current meters. This lack of calibration could affect the quality of the current metering measurements.

- Frequency of field work: The Hydrological Branch Offices check the station and collect the observer's booklets in the field. However, because of budget constraints this activity is now done only once every 4 months. The period of discharge measurements was 3 months per year and to less than 1 month per year. This is by far not sufficient. The reduction in field activities also seems to impact the dedication of observers in the field. In a number of cases SMEC has found that staff gauge sections were silted up and unreadable. In another case gauge levels were not noted for a couple of days. At a remarkable number of stations the observer was "out of town" and the observers' booklets could not be checked. The observers' booklets, together with the current metering sheets are sent to the Hydrology Department of the MoWR every 4 months.
- Data entry, processing, and quality control: Presently, there is no data entry, processing or quality control carried out at the Branch Offices, since this activity is the responsibility of the Hydrology Department Head Centre of the MoWR. From discussions with staff at the Hydrology Department it appeared that quality control is not always carried out as it should be because of insufficient staff.
- Gaps of missing data linked to many dysfunctions;

3.2.3 Network density

Using data relative to existing stations, we have analyzed the network based on different criteria. Note that only 405 stations features are available in the Excel data file collected.

Surface of upstream cathcment	Nb of stations	% of the total of stations
Non mentioned	21	5,2%
Area < 20 km²	16	4,0%
20 km²< Area < 40 km²	26	6,4%
40 km²< Area < 60 km²	34	8,4%
60 km²< Area < 80 km²	20	4,9%
80 km²< Area < 100 km²	20	4,9%
100 km²< Area < 140 km²	25	6,2%
140 km²< Area < 180 km²	26	6,4%
180 km²< Area < 250 km²	35	8,6%
250 km²< Area < 350 km²	23	5,7%
350 km²< Area < 450 km²	14	3,5%
450 km²< Area < 550 km²	16	4,0%
550 km²< Area < 650 km²	8	2,0%
650 km²< Area < 750 km²	3	0,7%
750 km²< Area < 1000 km²	12	3,0%
1000 km²< Area < 1500 km²	10	2,5%

1500 km²< Area < 2000 km²	15	3,7%
2000 km²< Area < 3000 km²	10	2,5%
3000 km²< Area < 4000 km²	10	2,5%
4000 km²< Area < 5000 km²	7	1,7%
5000 km²< Area < 8000 km²	11	2,7%
8000 km²< Area < 14000 km²	10	2,5%
14000 km²< Area < 20000 km²	16	4,0%
20000 km²< Area < 40000 km²	6	1,5%
40000 km²< Area < 60000 km²	3	0,7%
60000 km²< Area < 100000 km²	7	1,7%
100000 km²< Area < 180000 km²	1	0,2%

Figure 13 Number of stations per "upstream area" classes (table)

In Task 2, for designing the "ideal" network, we will used WMO recommendations in "Figure 20 Surface water- hydrological network design" as guides. The surface range is roughly between 1000 km² and 2000 km².

Compared to the surface values shown in "Figure 13 Number of stations per "upstream area" classes", only 6, 2% of the stations are in this WMO range. A large majority of stations (50%) have a drainage surface less than 250 km².

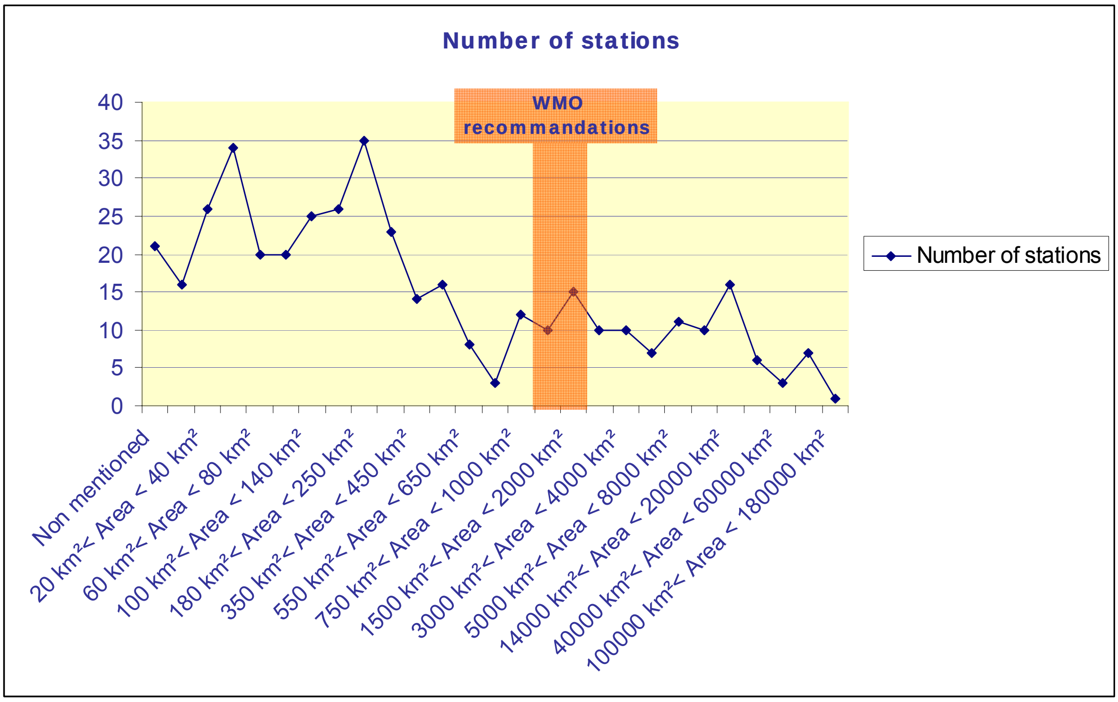


Figure 14 Number of stations per "upstream area" classes (graphical)

3.2.4 Equipment diagnosis approach

We proposed to go through the existing water network by using the "Computer-Integrated Manufacturing" (CIM), a method of manufacturing in which the entire production process is controlled by computer. Typically, it relies on closed-loop control processes, based on real-time input from sensors. The term "Computer Integrated Manufacturing" is both a method of manufacturing and the name of a computer-automated system in which individual engineering, production, marketing, and support functions of a manufacturing enterprise are organized.

In a CIM system functional areas such as design, analysis, planning, purchasing, cost accounting, inventory control, and distribution are linked through the computer with factory floor functions such as materials handling and management, providing direct control and monitoring of all process operations.

To adapt the CIM concept to Water domain, we have split the hydrometric network in five hierarchal levels, each one linking to the level below.

- Level 0 responsible for gathering information and is physically represented by all the measurement sensors.
- Level 1 brings together all the acquisition and Data Collected Platforms (DCP) so that information can be acquired and transferred.
- Level 2 is the communication support.
- Level 3 of the application is Real time applications, the communication and supervision station which controls transmissions throughout the transmission media and views outstations via synoptic screens on a real-time basis.
- Level 4 comprises the delayed time applications. Logged or transmitted data can be manipulated using a wide range of both general water resources and hydrological applications.

The C.I.M. concept is illustrated as followed in Figure 15 The C.I.M. pyramid concept adapted to Water domain

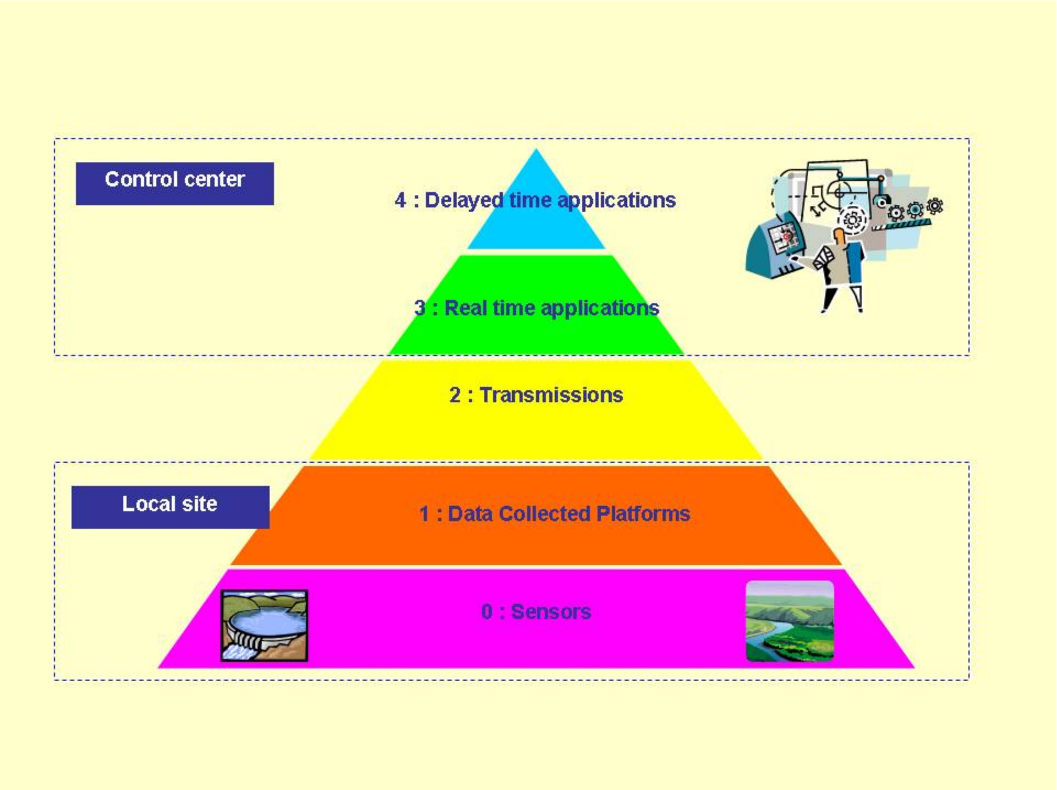


Figure 15 The C.I.M. pyramid concept adapted to Water domain

3.2.5 C.I.M. Level 0: Sensors

3.2.5.1 Staff gauge

The staff gauge is still today the reference for water level measurements. It is almost always associated with a real water level sensor. Staff gauges are installed on all sites visited on the project.

This element determines the exact position of the section of the gauge in the hydrometric reach and the change in altitude of the measured heights. This change in altitude is very important since any modification leads to a modification of the relationship between water level and flow (invalidity of the station).

3.2.5.2 Water level recorder (float)

When there is either no observer available and/or a (quasi) continuous record of water level is required, some water level recorders with float have been installed.

Even such equipment offer qualities such as : simplicity, robustness , high strength, it offers also some strong disadvantages:

- Civil engineering works sometimes very important,
- Very uncertain results when used in rivers with high sediment transport (Figure 16 Water level recorder)
- Sensitivity: depends much on the definition of the mechanical parts and the maintenance
- Precision: linked to the resistant couple "pulley-graphical recording system", and to the diameter of the float and the pulley

The theoretical precision given by the manufacturer can come down to the mm in better conditions, in practice one cannot expect better results more than 5 mm, with is excellent in did. The use of a chart as recording medium has also largely become outdated being replaced by electronic data loggers. It has been introduce in a large number of stations, inside the original water level recorder using paper chart. The main problem with the chart system lies with the amount of time required for processing. The recorded hydrograph has to be at best digitised and thus transformed into a numerical record, or at worst analyzed manually, measuring off levels and corresponding times.

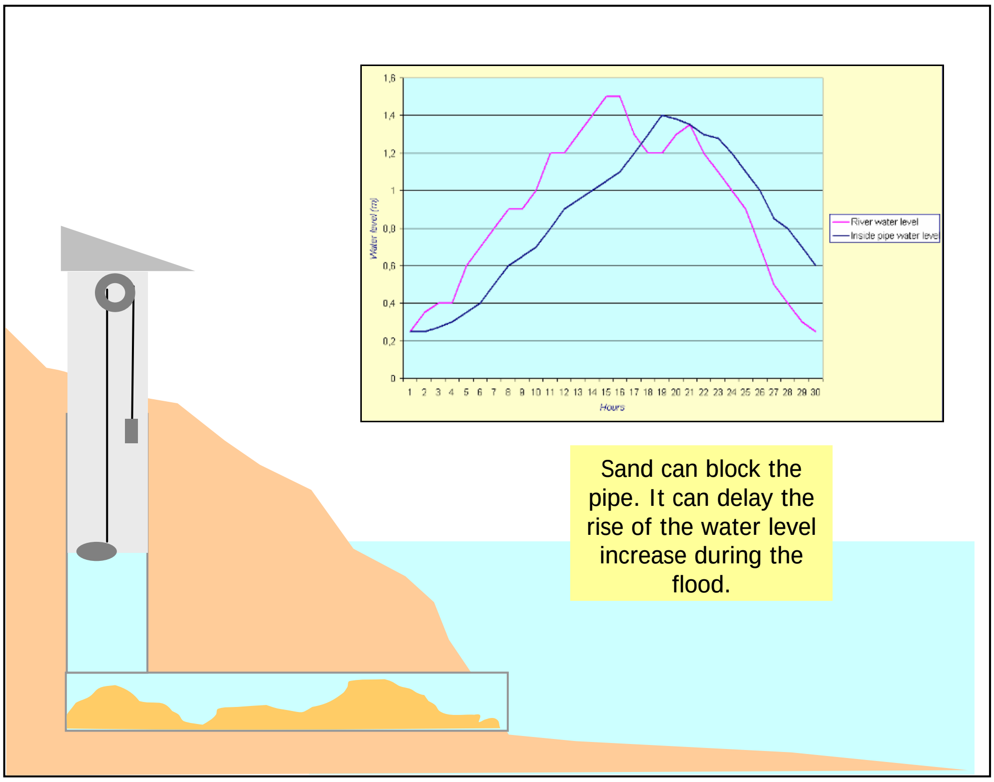


Figure 16 Water level recorder obstructed by sediment

3.2.5.3 Radar sensor with electronic logger

Aerial sensor loggers have been installed on few numbers of stations.

Principles: the distance between an emitter /receptor of electromagnetic waves and the water level is deducted to the time of course of these waves. If c is the velocity of propagation of the waves and t the necessary time required for the going and the coming of a perpendicular wave, then h = c*t/2, where h = distance of the emitter at the water level surface.

The radar emitter (called transducer) possesses the property of converting the impulsions of electric energy into magnetic waves or vice versa.

It is associated to an electronic circuit which engenders the electric energy at high frequency, transmits it and measure the time spent between the sending and the return of the signal.

Even the choice of radar sensor is excellent, the equipment already installed, meet some trouble linked to software setup.

This problem focuses on the fact, that hydrometric company must be installed (or represented) in Ethiopia with a technical staff, capable to offer a real assistance for maintenance.

3.2.6 C.I.M. Level 2: Transmission

Level 1 of CIM is not concerned in this architecture, as data collection is done by observers.

For some sites where water level information is important for flood management on downstream dams, transmissions are implemented between observers and the Ministry of Water Resource at Addis Ababa. Transmissions use radio on the HF (High Frequency) band with SSB (or USB) modulation.

In this HF band, transmissions are done by surface waves. The propagation is done by reflect on the ionized layers which surround the ground (Ionosphere). It results great ranges of diffusion, but associated to certain instability of the signal linked to variations of the environment (weather).

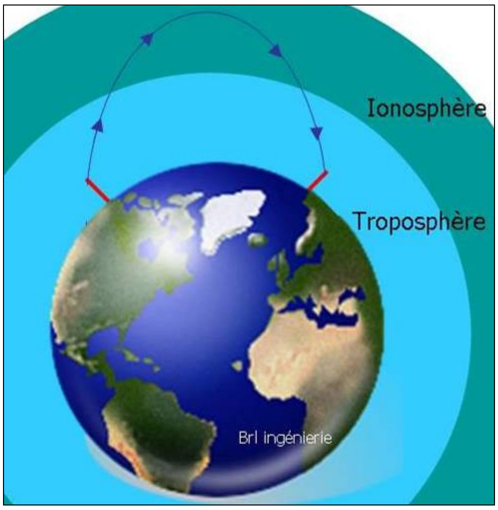


Figure 17 Range of the ionospheric waves

Note that confidentiality of transmissions is not warranty, as the range of transmission cross borders of Ethiopia.

3.2.7 C.I.M. Level 4: Data management

Level 3 of CIM is not concerned in this architecture, as data collection is done by observers.

Data collected are archived in HYDATA software. HYDATA has been designed to handle the types of data most often encountered in hydrological context. Both daily and monthly data can be stored. Daily flow may be calculated automatically using stored rating equations (Level / Flow).

HYDATA can treat usual hydro - meteorological data (rainfall, wind, discharge, water level…), but also some user-defined data such as temperature, electrical conductivity …).

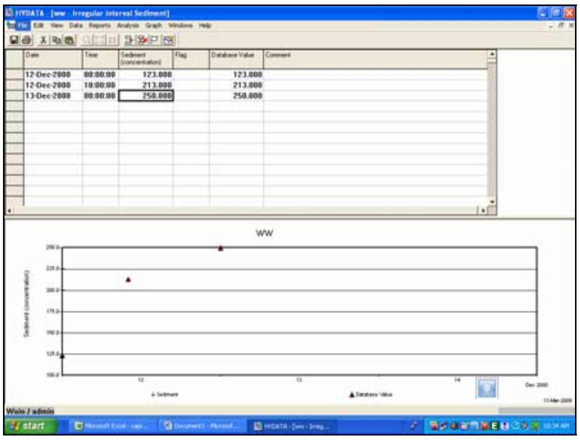


Figure 18 HYDATA interface (quality)

Three major remarks can be done on HYDATA:

- First, the software is not published any more. Then, there is no more maintenance, nor evolution of it.
- Its computer architecture (standalone system), which imposed to centralize in the MoWR (Addis Ababa) the data updating for all the territory of Ethiopia. HYDATA uses Access database which is not convenient for a large amount of data. To avoid this problem, the Hydrology staff of the MoWR has segmented the global database to a database dedicated to each station. Then, no global vision is possible;
- HYDATA don't provided any cartographic interface to analyze spatially climatologic and hydrologic phenomena;

Comments:

The Terms of Reference request to build a quality database to be linked to the hydrological database. Considering the needs to analyze quality close to hydrology, we consider that using HYDATA for these two purposed (Quality and Quantity) will be optimal, and we have tested the feasibility as shown in the Figure 18 HYDATA interface.

3.3 GROUNDWATER NETWORK

3.3.1 Diagnosis approach

Before making conception of a groundwater network (quality and quantity), some precisions have to be given on principal threats which make vulnerability of groundwater resources.

3.3.2 Review of the existing situation of the quantity network

No permanent network is installed for measuring and estimating the quantity of groundwater abstraction and related changes in the groundwater. In some urban zones, well fields used for drinkable water, are equipped with water meters (for production estimation and billing) and occasionally with associated water level sensors installed with the borehole pumps, such as in Dire Dawa and Mekele Towns.

As these sensors are used for a operational purpose, they can be efficient for a groundwater monitoring as the water level will be affected by pump aspiration.

Linked to this aspect, no time series of the groundwater level are available for long period. This lack of information obstructs a precise estimate of groundwater resources, as no relation can be define between aquifer response and recharge by rain or abstraction by wells.

Some time series very limited in terms of duration (similar to “snap shots”) are available on few aquifers, but due to the duration, no extrapolation can be done on seasonal or long term changes.

Without any permanent monitoring programs for groundwater, no reliable resources evaluation can be envisaged.

3.3.3 Review of the existing situation of the quality network

3.3.3.1 Former projects

A large project was envisaged few years ago, to install up to 50 monitoring wells across Ethiopia. The objective was to monitor the impact of climate change and environment on groundwater, by measuring hydraulic head, EC, pH and selected ions. As of 2009, no monitoring wells have been installed in Ethiopia.

During the 1960’s, another monitoring network of groundwater salinity was envisaged in the central Awash basin in relation with the modern irrigable agricultural development in the rift valley. Rapidly, all monitoring wells have been abandoned. However, some data can be found on printed version in the Ministry of agriculture, and in irrigation farms (Wonji, Metehar and Amibara).

Note that some major dams also have piezometers to monitor the hydraulic head. In another project, five piezometers have been installed in 2001-2003 to monitor Akaki well field which supplies Addis Ababa city in drinking water. Currently, these piezometers are out of order.

3.3.3.2 Current projects

The Geological Survey of Ethiopia (GSE) undertakes groundwater investigation all over the country and has acquired a large amount of geological and hydro-geological data. The GSE has covered 35 % of the land mass of Ethiopia with 1:250,000 scale hydro- geological maps and associated reports.

The regional bureaus of the MoWR are in charge of the water resource development. They have also acquired informations relative to groundwater resource, which must archive in ENGDA software centralized in the MoWR (Addis Ababa).

Universities, particularly, Addis Ababa University, have collected groundwater data as part of their postgraduate program in groundwater. Every year, several M.Sc. theses are presented which contain a good deal of groundwater information.

To finalize, NGOs, consultants and contractors are working on groundwater development. No mechanism is defined to enforce these organizations to deliver data to the MowR. However, data, collected by these organizations, vary in terms of details. Some data related to parameters collected are very detailed, but a large majority of measurement sites has no geographical coordinates.

Currently, one person is in charge of collecting, processing and analyzing groundwater quality. This fact has to be mentioned, as groundwaters are essential for the sustainable development of Ethiopia.

3.3.4 Data collection and Groundwater Database

A National Groundwater Database (ENGDA) has been established in 2005 under EGRAP to archive and disseminate groundwater data. EGRAP is a national joint program between the Ministry of Water Resources and Geological Survey of Ethiopia. The project aims to produce maps relative to the groundwater water resource of Ethiopia.

ENGDA is a powerful database which permits to record all essential information relative to springs and boreholes. The principal features of springs or boreholes can be introduced, such as : location (X, Y, Z), geological and lithological profile, diameter, depth, position of the screens, pumping test results, water utilization, water chemistry (major ions, microbiology, heavy metals, organic pollutants, isotopes,…), water table evolutions,…

But data archived in ENGDA database, are updated continuously. A large majority of the recent boreholes is absent, and then ENGDA, which is a very efficient software, decreases progressively in terms of efficiency for groundwater management.

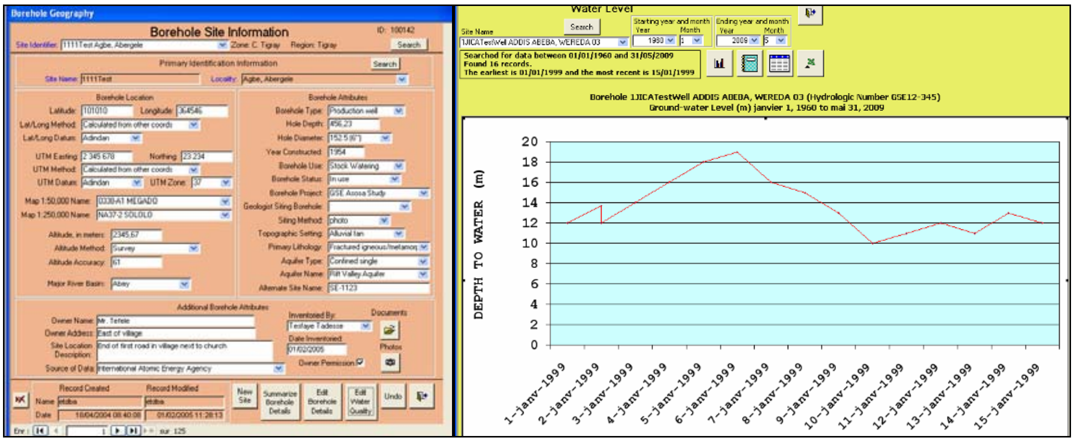


Figure 19 ENGDA Man Machine Interface

Two major remarks can be done on ENGDA:

- The absence of cartographic interface which offers no possibility to locate wells and springs, or to produce thematic maps for quality interpretation for example.
- Its computer architecture (standalone system), which imposed to centralize in the MoWR (Addis Ababa), all the data updating for all the territory of Ethiopia.

Note that to facilitate the Database update, and to limit the time spent for collecting data, the MoWR could required to drilling companies, to declare all the wells in production, by creating a dedicated folder which includes all data required for ENGDA. This "constraint" will be easy to be implemented, face to the few number of drilling companies installed in Ethiopia.

4. Improving Observation and Data Collection Systems

4.1 NETWORK DESIGN

4.1.1 Surface water

For Surface water, the Terms of Reference make clear reference to a design carried out "in relation with the existing hydrological network". Of interest is the fact that access has clearly played a major role in the choice of site locations. The main road network is also shown on this map. Because of the difficult nature of the terrain many of the roads run close to the watershed of many catchments and as a result gauge relatively small upland areas of the basin. The continued expansion of the roadwork may mean that there are now other parts of different basins which could be accessed more easily than 10 or 15 years ago. This will be kept in mind.

But, in the way to build optimal network, we have designed it, based on hydrological, geological and socio-economical criteria. The result will be then, compared to the existing network, to complete it, if necessary.

4.1.1.1 Hydrological stations

4.1.1.1.1 General

The main objective of the stream-gauging network is to obtain information on the availability of surface-water resources, their geographical distribution, and their variability in time. Magnitude and frequency of floods and droughts are of particular importance in this regard.

4.1.1.1.2 Criteria for network design

An optimum network would take into account different criteria such as:

- Population density also affects network design. It is almost impossible to install and operate, in a satisfactory way, a number of stations where population is sparse. For example, to set up more than two gauges on a catchment of 1 000 km², when the population of the area is only 100 people. Besides, it is difficult even to find observers in thinly-populated areas where access is poor.
- In general, a sufficient number of streamflow stations should be located to permit interpolation of discharge between the stations on the main rivers. But computing discharges are time consuming, so specific locations will be governed by topographic and climatic considerations. In this context, when the tributary flow is representing a special interest, in such a case, a station on the tributary will be required. Criteria such as Horton numeration or surface catchments can be useful.
- Wherever possible, the base stations should be located on streams with natural regimes. Where this is impractical (hydroelectric plants or control dams), it may be necessary to establish additional stations on canals or reservoirs to obtain the necessary data to reconstruct the natural flows at the base stations.
- Stations should be located on the lower reaches of the major rivers of the country, immediately above the river mouths (usually above tidal influence), or where the rivers cross borders. Stations should also be located where rivers issue from mountains and above the points of withdrawal for irrigation water. Other hydrometric stations are situated at points, such as where the discharge varies to a considerable extent, below the points of entry of the major tributaries, at the outlets from lakes, and at those locations where large structures are likely to be built.

Densities recommended by WMO, as shown in "Figure 20 Surface water- hydrological network design" serve as guides in considering a basic network.

Physiographic unit	Minimum density per station (area in km² per station)
Coastal	2 750
Interior plains	1 875
Small islands	300
Mountainous	1000
Hilly/undulating	1 875
Polar / Arid	20 000

Table 6 Density for Hydrological stations

Based on these recommendations, we proposed to design the hydrological network following different criteria shown in the "Figure 20 Surface water- hydrological network design":

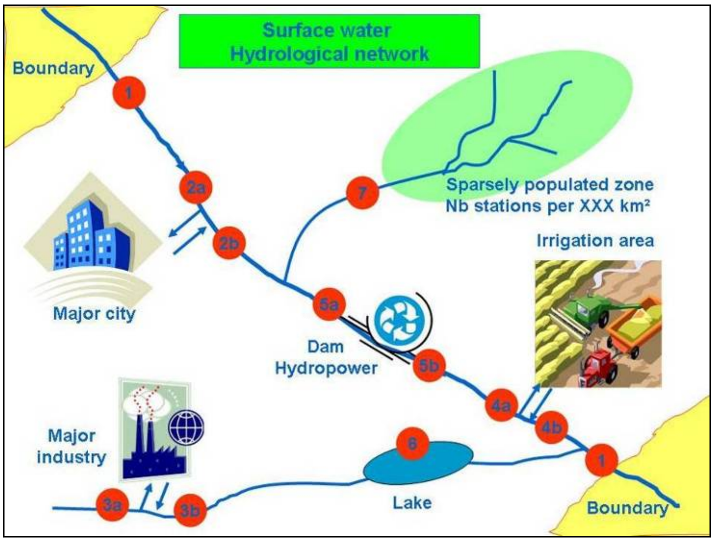


Figure 20 Surface water- hydrological network design

N°	Location	Objectives	Suggested measurement frequency	Suggested Transmission Frequency
1	Closed to borders	Controlling the quantity (and quality) at the entry and the exit of the national territory	2 times / Day or 1 time per hour if a dam is installed upstream closed to the border	1 time / Week
2a	Upstream the abstraction of water supplies	Controlling the quantity (and quality) of the river in an altered zone	1 time / Hour linked to the social usage of potable water or 8 time/Day is the social usage is well known	1 time / Week or 1 time / Day if the zone is very stressed in terms of quality
2b	Downstream the outlet of sewage networks			
3a	Upstream the abstraction of factories	Controlling the quantity (and quality) of the river in an altered zone	1 time / Hour linked to the industrial process of the factories	1 time / Week or 1 time / Day if the zone is very stressed in terms of quality
3b	Downstream the outlet of sewage networks of the factories			
4a	Upstream the abstraction of irrigation perimeters	Controlling the quantity (and quality) of the river in an altered zone	2 or 4 times/Day, linked to the culture method (irrigation schedule)	1 time / Week or 1 time / Day if the zone is very stressed in terms of quality
4b	Downstream the outlet of drainage networks of the irrigation perimeters			
5a	Upstream the dam	Controlling the quantity (and quality) of the river in an altered zone and managing floods	1 time / Hour during flood crisis or 4 times / Day for environmental survey	1 time / Hour during flood crisis or 1 time/Day otherwise
5b	Downstream the dam			
6	In the lake closed to the quality station	Controlling the quantity for an environmental survey	2 times / Day for environmental survey	1 time / Week
7	Downstream a tributary	Controlling the quantity for an environmental survey	2 times / Day for environmental survey	1 time / Week

Table 7 Surface water - hydrological – Measurement and data transmission requests

Measurement Frequency and Transmission Frequency parameters are just suggested. It has to be defined linked to water basin configurations.

4.1.1.1.3 Aggregation rules

If different kinds of stations should be located on a same river segment, based on the design methodology, then aggregation rules should be applied (on measurement frequency criteria) as followed:

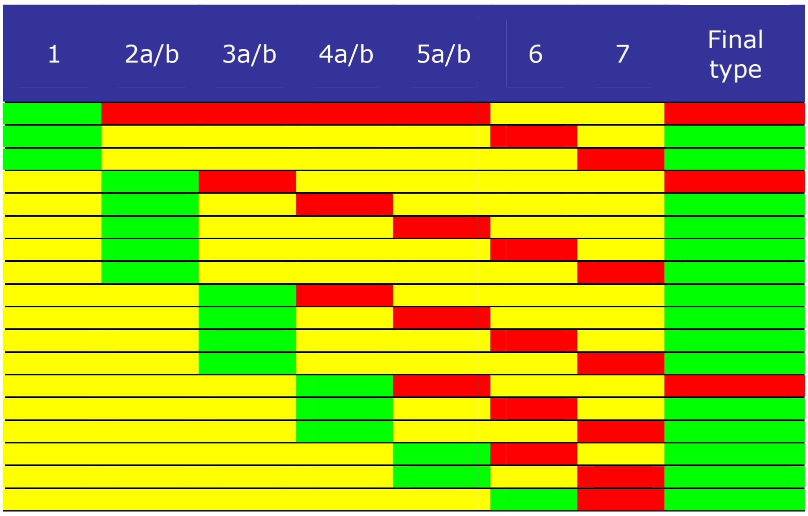


Table 8 Surface water - hydrological – Aggregation rules

4.1.1.1.4 Design of the Surface water- hydrology network

HYDROLOGY STATION PROPOSED LOCATIONS

Based on the methodology presented here before, the hydrology station location has been produced by defining:

- Borders : transboundary type,
- Major tributaries, density, irrigation, towns, dams : main type,
- Lake type,
- All existing stations not involved in the preceding list (surface basin < 1000 km²),

Results are produced in "Figure 21 Proposed locations for surface- water level stations", are listed in the following tables.

	ABBAY	AWASH	BARO AKOBO	DENAKIL	GENALE DAWA
Transboundary stations	5	0	4	0	4
Main station stations	78	38	18	8	40
Lake stations	4	8	0	2	0
Secondary station	95	40	17	6	9
TOTAL	182	86	39	16	53

	MEREB	OMO GIBE	RIFT VALLY	TEKEZE	WABI SHEBELE	TOTAL
Transboundary stations	2	1	0	4	2	22
Main station stations	0	21	15	20	32	270
Lake stations	0	1	9	0	0	24
Secondary station	1	32	36	15	23	274
TOTAL	3	55	60	39	57	590

Table 9 Surface water level stations (density)

A detailed list of envisaged location stations can be found in annex n°1 to the present document.

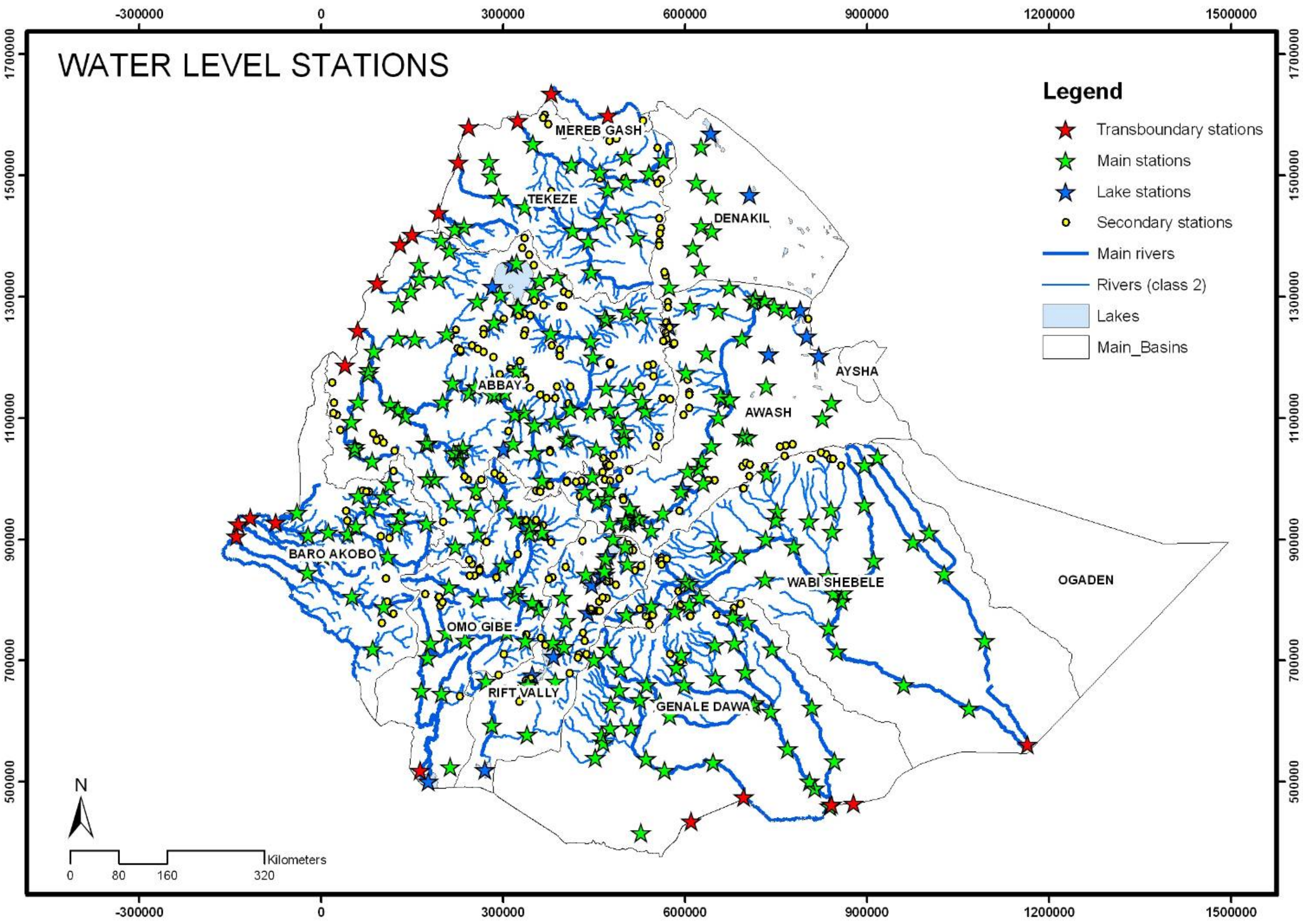


Figure 21 Proposed locations for surface- water level stations

4.1.1.2 Water quality stations

4.1.1.2.1 General

Sampling strategy will be quite different for different kinds of water bodies. It will be based on the program objectives, which in fact, will precisely define the best locations for sampling in a river, lake or groundwater system. But the sampling location will be also influenced by hydraulic context. Rivers mix completely within distances ranging from several kilometers to a few hundred kilometers of any point source of pollution. Lakes may be vertically stratified because of temperature or inflows of high density saline water. Groundwater tends to flow very slowly, with no surface indication of the changes in its solutes taking place below.

Then, choosing sampling locations will be based first, on collecting relevant information about the region to be monitored. The information sought includes geological, hydrological, and demographic aspects, as well as the number of lakes and streams, locations of aquifers, climatic conditions in the catchment area, municipal and industrial centers, current water intakes and waste outlets, irrigation schedules, flow regulation (dams), water uses, lake water quality.

4.1.1.2.2 Surface water quality station

The number of sampling points in a river depends on the hydrology and the water uses. For example, in order to determine the effect of an effluent discharge on a receiving stream, sampling locations upstream and downstream of the discharge would be required. In other cases, both location and frequency of sampling will be determined by anti-pollution laws or by a requirement for a specific use of a water body. For example, a permit to discharge surface waters may outline details of monitoring, such as location, number of samples, frequency and parameters to analyze. As a minimum network, records of water quality should be obtained at the densities shown in the following table:

Physiographic unit	Minimum density per station (area in km2 per station)
Coastal	55 000
Interior plains	37 500
Small islands	6 000
Mountainous	20 000
Hilly/undulating	47 500
Polar / Arid	200 000

Table 10 Density for Surface water - Quality network design

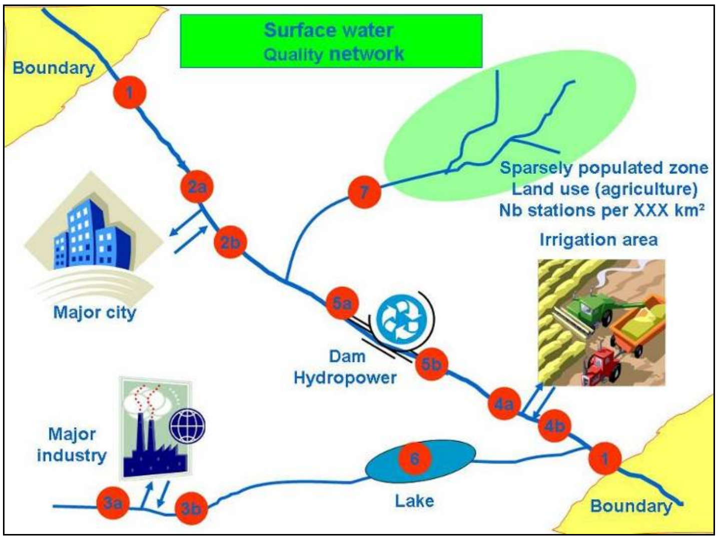


Figure 22 Surface water - Quality network design

Note that the distance downstream to the point of complete mixing is roughly proportional to the stream velocity and to the square of the width of the channel. Rivers are usually sufficiently shallow that vertical homogeneity is quickly attained below a source of pollution. Lateral mixing is usually much more slowly attained. Thus, wide swift-flowing rivers may not be completely mixed for many kilometers downstream from the input point.

Based on our experience of permanent in – situ measurement, we have considered that water quality survey will be done manually, except for measurement campaign which will considered temporary on site measurement.

The fundamental concepts applied in designing the water quality monitoring network have been deduced from the objectives of the monitoring program. The water quality monitoring network objectives have been defined as follows:

a) To reveal the baseline conditions, long-term changes and trends in the water-course system.

b) To provide information on the past, present and future effects of significant natural and anthropogenic activities on the aquatic environment including water projects such as large irrigations, dams, diversions, industrial, agricultural and urban development's.

c) To indicate the state of health of surface waters and to detect any signs of deterioration in water quality

d) To identify areas in need of improvement and establishment of priorities.

In order to meet the objectives shown above, the monitoring networks have included four basic types of monitoring stations:

- Baseline stations
- Trend stations
- Impact stations
- Transboundary stations
- Lake stations

1. Baseline stations

Baseline stations are necessary to establish the natural water quality conditions. They will be used to make comparisons with stations that are exposed to significant and direct anthropogenic impacts. As far as the realities on the ground permit, the baseline stations will be located in undisturbed upstream river stretches where no direct, diffuse or point-source of pollutants is likely to be found.

2. Trend stations

Trend stations are important to look at the spatial and temporal changes in water quality. They will be mainly used to monitor long-term changes in water quality related to a variety of pollution sources and land uses. The trend stations will also provide useful information for identification of causes or influences on measured conditions or identified trends. Together with the impact stations, the trend stations will respond to objectives (c) and (d).

3. Impact stations

The purpose of having impact stations in the network is to monitor the short and medium term impacts of pollutants generated from major activities that include large irrigation sites, major urban towns and cities, industrial activities and hydropower dams. These type of stations will respond to objective (2- trend) and (3 -impact). The impact stations will be basically located at upstream and downstream points from the sources of pollutants. Determining a site for impact stations also has its own particular problems. If these stations are too far apart, there may be no relationship between them. If they are located too close together, there may not be a detectable difference. Therefore it was given due attention in the process.

In order to capture most of the medium and large urban settlements in Ethiopia, all towns labeled as zonal and regional capitals are considered in the site selection process. Industrial activities in Ethiopia are largely concentrated in and around urban settlements. Thus, considering zonal and regional capitals in the site selection process will at the same time help to capture the impact of industrial activities.

N°	Location	Objectives
1	Closed to borders	Controlling the quality at the entry and the exit of the national territory
2a	Upstream the intakes of water supplies	Controlling the quality at of the river in an altered zone
2b	Downstream the outlet of sewage networks	
3a	Upstream the intake of factories	Controlling the quality at of the river in an altered zone
3b	Downstream the outlet of sewage networks of the factories	
4a	Upstream the intake of irrigation perimeters	Controlling the quality at of the river in an altered zone
4b	Downstream the outlet of drainage networks of the irrigation perimeters	
5a	Upstream the dam	Controlling the quality at of the river in an altered zone
5b	Downstream the dam	
6	In the lake closed to the quality station	Controlling the quality for an environmental survey
7	Downstream a tributary	Controlling the quality for an environmental survey

Table 11 Surface water - hydrological – Measurement and data transmission requests

If different kinds of stations should be located on a same river segment, based on the design methodology, then aggregation rules should be applied as followed:

1	2a/b	3a/b	4a/b	5a/b	6	7	Final type
green	red	red	red	red	yellow	yellow	green
green	yellow	yellow	yellow	yellow	red	yellow	green
green	yellow	yellow	yellow	yellow	yellow	red	green
yellow	green	red	yellow	yellow	yellow	yellow	red
yellow	green	yellow	red	yellow	yellow	yellow	green
yellow	green	yellow	yellow	red	yellow	yellow	green
yellow	green	yellow	yellow	yellow	red	yellow	green
yellow	green	yellow	yellow	yellow	yellow	red	green
yellow	yellow	green	red	yellow	yellow	yellow	green
yellow	yellow	green	yellow	red	yellow	yellow	red
yellow	yellow	green	yellow	yellow	red	yellow	red
yellow	yellow	green	yellow	yellow	yellow	red	red
yellow	yellow	yellow	green	red	yellow	yellow	red
yellow	yellow	yellow	green	yellow	red	yellow	red
yellow	yellow	yellow	green	yellow	yellow	red	red
yellow	yellow	yellow	yellow	green	red	yellow	red
yellow	yellow	yellow	yellow	green	yellow	red	red
yellow	yellow	yellow	yellow	yellow	green	red	red

Table 12 Surface water – Water quality – Aggregation rules

For lake or reservoir, specific recommendations are proposed to implement a quality network inside the water body.

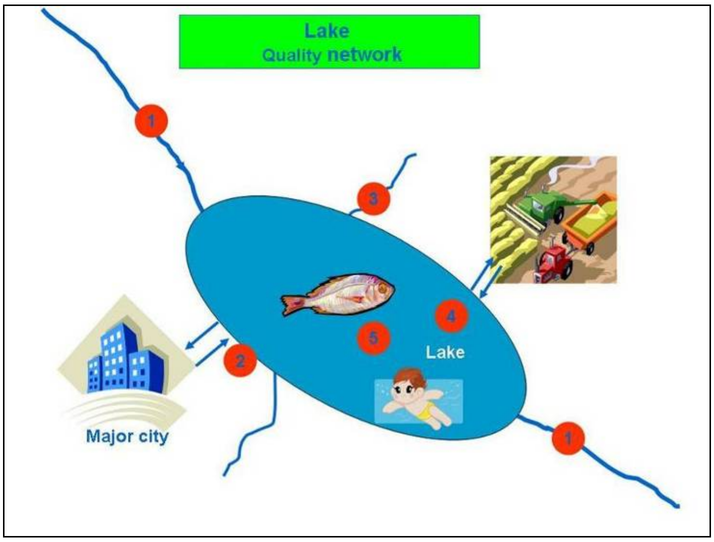


Figure 23 Lake - Quality network design

For lake stations, the recommended practice is to sample five consecutive days during the warmest part of the year and five consecutive days every quarter. Special cases include temperate-zone lakes that experience stratification. These should be sampled at least six times a year, together with the occasional random sample, to cover the following periods: during open water prior to summer stratification, during mixing following summer stratification, and during the periods of runoff. Similarly, additional samples of rivers should be taken, if possible, after storm events and during runoff.

4.1.1.2.3 Design of the Surface water- Quality network

Based on the monitoring objectives, we have incorporated in the GIS, the major sources of pollutants and the ultimate sites needed to monitor them. The GIS model network have considered the impacts of major cities, in this case the regional and zonal capitals, large irrigation sites both potential and developed, hydropower dams, and industrial activities. The reason behind selecting regional and zonal capitals for the model is apparently due to the comparatively significant urban population they contain. Though there are a number of secluded areas for industrial zones in different parts of the country, they are not yet developed. Practically, the majority of industrial establishments are found in or around urban settlements. Therefore, incorporating zonal and regional capitals in the design model have an additional advantage of capturing the impacts of industrial activities.

The resulting stations from the GIS approach, give the following output evaluation whose name, location, and type are described in Annex2 are macro location of the stations that compose the water quality monitoring network. These macro locations are intended to show the general area of the surface water bodies from which samples are to be taken. The actual specific locations from which samples should be taken are situated within the macro locations but must be further verified at later stages during the first few sampling campaigns using the following criteria's. The criteria's for selecting the actual specific sites include: representativeness of the sampling site, safety and security, presence of disturbing influences and availability of stable stream bed.

Explanations relative to types (baseline, trend…) can be found in the precedent chapter.

	ABBAY	AWASH	BARO AKOBO	DENAKIL	GENALE DAWA
Baseline stations	1	1	3	0	2
Trend stations	5	11	3	0	9
Transboundary stations	1	0	1	0	2
Impact stations	30	11	6	0	5
Lake stations	2	6	0	3	0
TOTAL	37	23	13	0	18

	MEREB	OMO GIBE	RIFT VALLY	TEKEZE	WABI SHEBELE	TOTAL
Baseline stations	1	1	0	2	3	14
Trend stations	2	4	0	7	10	51
Transboundary stations	0	1	0	3	1	9
Impact stations	0	8	7	3	7	77
Lake stations	0	1	8	0	0	20
TOTAL	3	14	7	15	21	151

Table 13 Surface water quality stations (density)

A detailed list of envisaged location stations can be found in annex n°2 to the present document.

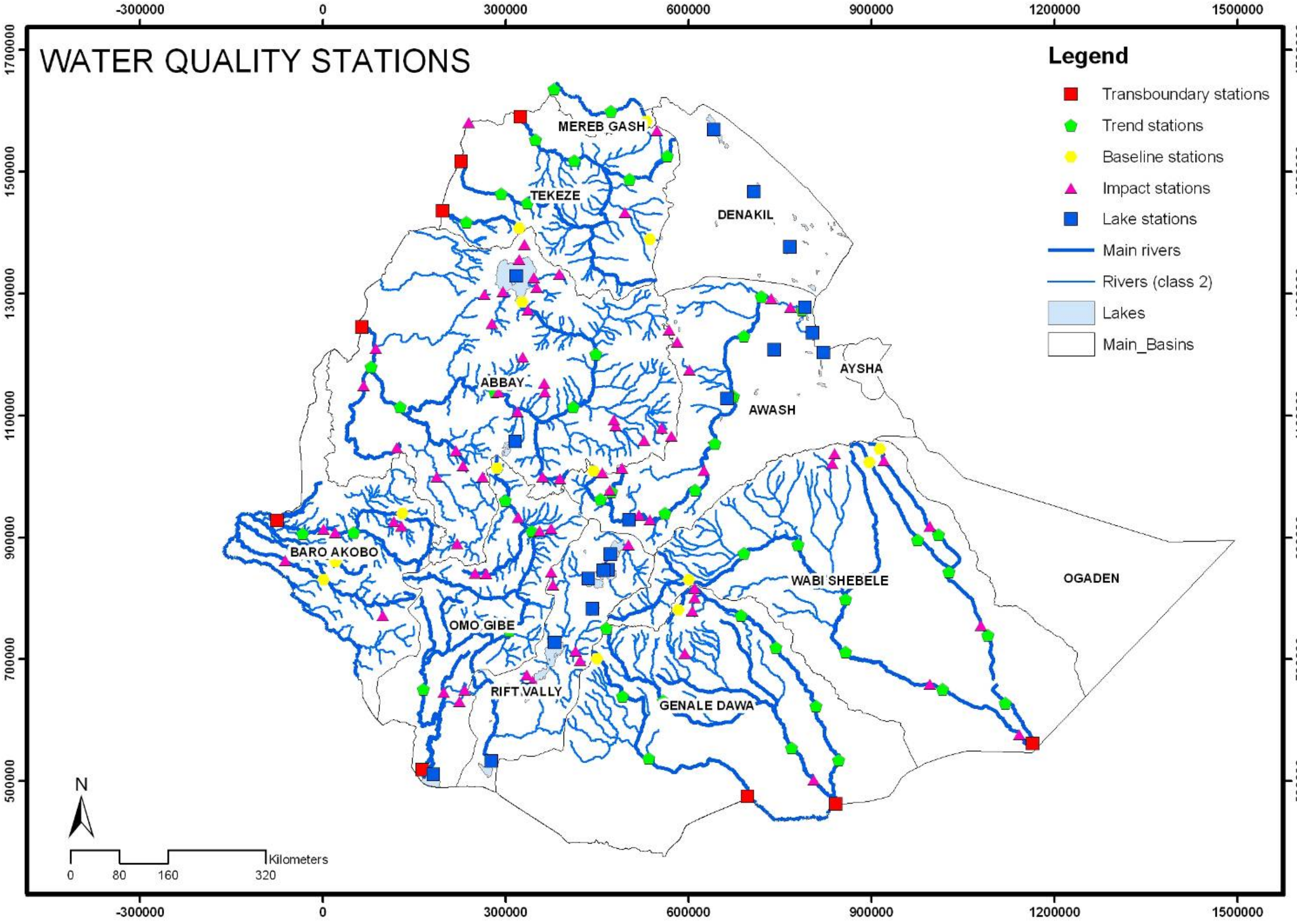


Figure 24 Proposed locations for - water quality stations

4.1.1.3 Surface water quality and quantity station priority

4.1.1.3.1 Type of stations

Based on the network levels presented the following classification of stations is introduced:

- Primary stations, maintained as key stations, principal stations or bench mark stations, where measurements are continued for a long period of time to generate representative flow series of the river system and provide general coverage of a region.
- Secondary stations, which are essentially short duration stations intended to be operated only for such a length of period, which is sufficient to establish the flow characteristics of the river or stream, relative to those of a basin gauged by a primary station.
- Special purpose stations usually required for the planning and design of projects or special investigations and are discontinued when their purpose is served. The purpose could vary from design, management and operation of the project to monitoring and fulfillment of legal agreements between co-basin states. The primary as well as secondary stations may also, in time serve as special purpose stations.

In designing a network all types of stations must be considered simultaneously.

Based on our project, all surface water stations will be from the Primary type.

4.1.1.3.2 Criteria for selecting station

MINIMUM NETWORK

A minimum network should include at least one primary station established:

- in each climatological and physiographic area in a State.
- in river or stream, which flows through more than one State, and should be installed at the State boundary
- in those basins with potential for future development.

A minimum network should also include special stations. Where a project is of particular socioeconomic importance to a State or Region, such as dams for example, it is essential that a gauging station is established for planning, design and possibly operational purposes.

NETWORKS FOR LARGE RIVER BASINS

A primary station might be planned at a point on the main river where the mean discharge attains its maximum value.

For rivers flowing across the plains, this site is usually in the downstream part of the river, immediately upstream of the point where the river normally divides itself into branches before joining the sea or a lake or crosses a State boundary.

In the case of mountainous rivers, it is the point where water leaves the mountainous reach and enters the plain land. Subsequent stations are established at sites where significant changes in the volume of flow are noticed viz., below the confluence of a major tributary or at the outflow point of a lake etc.

If a suitable location is not available below a confluence, the sites can be located above the confluence, preferably on the tributary. While establishing sites downstream of a confluence, care should be taken to ensure that no other small stream joins the main river so as to avoid erroneous assessment of the contribution of the tributary to the main river.

In the case of a large river originating in mountains, though the major contribution is from upper regions of the basin, several stations may have to be located in the downstream stretch of the river. Such stations are intended to provide an inventory of water loss from the channel by way of evaporation, infiltration, and by way of utilization for irrigation, power generation, industrial and other domestic needs.

The distance between two stations on the same river may vary from thirty to several hundred kilometers, depending on the volume of flow. The drainage areas computed from origin up to consecutive observation sites on a large river should preferably differ by more than 10% so that the difference in quantities of flow is significant. The uncertainties in discharge values particularly for high flows are unlikely to be less than +/- 10%. However, every reasonable attempt should be made to minimize these uncertainties. The above uncertainties may affect the location of stations.

NETWORKS FOR SMALL RIVER BASINS

The criteria mentioned for large river basin are applicable to a river basin having a large area and well developed stream system. A different approach is to be adopted in dealing with small independent rivers, which flow directly through the border or into the sea. In such cases, the first hydrological observation station might be established on a stream that is typical of the region and then further stations could be added to the network so as to widely cover the area.

Low flow area must also be included in the network. Absence of a station on a low flow stream may lead to wrong conclusions on the water potential of the area as a whole, evaluated on the basis of the flow in the high flow streams. Thus, great care is to be exercised in designing the network to ensure that all distinct hydrologic areas are adequately covered.

It is not possible to operate and maintain gauging stations on all the smaller watercourses. Therefore, representative basins have to be selected and the data from those are used to develop techniques for estimating flows for similar ungauged sites.

PRIORITISATION SYSTEM

It is suggested that in the first instance the "ideal" network size is determined. In determining the network all potential users of the data should be consulted. Each station in the "ideal" network should be prioritized. In order to do this a simple prioritization system is useful. This prioritization system could be a simple one such as follows:

Category	Priority	Relative Importance
A	High	Major, multi-purpose water resources development site, State boundary river, operation of major scheme, major ungauged basin, heavily polluted major water supply source
B	Medium	Medium scale water resources development project site, secondary basin, industrial development area (i.e. potential water quality problems)
C	Low	Minor irrigation project site, secondary gauging station on tertiary tributary, major water course but already extensively gauged

Level of interest	Category	Location	Objectives
National	A	Closed to borders	Controlling the quantity (and quality) at the entry and the exit of the national territory
	A	Downstream the dam	Managing drought and estimating hydroelectricity production
	A	Downstream a major tributary	Controlling the quantity for an environmental survey
	B	In the lake closed to the quality station	Controlling the quantity for an environmental survey
Regional	B	Upstream the dam	Controlling the quantity (and quality) of river in an altered zone and managing floods
	B	Downstream the outlet of sewage networks (Urban zone)	Managing drought (in quality) in an altered zone
	B	Downstream the outlet of drainage networks of the irrigation perimeters	Managing drought (in quality) in an altered zone
	B	Downstream the outlet of sewage networks of the factories	Managing drought (in quality) in an altered zone
Local	C	Upstream the abstraction of water supplies	Controlling the quantity (and quality) of the river in an altered zone
	C	Upstream the abstraction of factories	Controlling the quantity (and quality) of the river in an altered zone
	C	Upstream the abstraction of irrigation perimeters	Controlling the quantity (and quality) of the river in an altered zone

Figure 25 Grid of criteria evaluation

4.1.1.4 Sediment discharge and bed load

4.1.1.4.1 General

Routine sediment measurements at stations are usually restricted to sampling the suspended load at flow gauging stations. In this sense, sediment is looked at as a "quality" parameter of the water. Although the present need for sediment data may be satisfied with the existing network, new needs could emerge in relation to various kinds of projects or studies, e.g. hydraulic structures, reservoirs, quality aspects.

4.1.1.4.2 General criteria for network design

For the hydrological network, priority is given to the need for stream flow data and the guidelines set out in the corresponding section of the manual on stream flow apply. For possible supplementary stations in which emphasis is given on sediment, the following general principles should be followed:

- assess the existing conditions within the watershed;
- define clearly the monitoring objectives and the data needs;

- establish the required time table, the frequency and periods of observation;
- make a thorough evaluation of the geomorphic setting in the reaches where useful measurement stations were selected.

Obviously, the site selection will be a compromise between many and different criteria; it will be the responsibility of the network designer to make a careful choice, bearing in mind the need to use the available resources in an optimal way.

4.1.1.4.3 Classification for sediment measurement sites

The three categories defined in the general classification of stream flow measurements, as presented in the corresponding chapter, also apply to the stations where sediment is gauged together with the flow. Most often, no particular categories are made for sediment measurements. However, specific categories may be useful to define specific sediment gauging strategies based on the particular sedimentology of each. There are no such requirements as density per unit area (except those suggested by WMO as described in the newt chapter), rather a network adapted to the specificity of the catchment in terms of geomorphology and sediment production, transport and deposition. This additional classification (or differentiation) of measurement sites may be made in different ways (see also the Sediment Measurements). One considers the kind of the sediment moving through the considered reach:

- 1. suspended load mainly wash load, composed of clay or fine silt, with little sand content; negligible bed load;
- 2. suspended load mainly containing bed material load with significant proportions of sand; limited bed load;
- 3. suspended load mainly containing bed material load with high proportions of coarse sediment; significant bed load.

Besides the classification based on the composition of the transported sediment load, the composition of the bed material is important as well as the degree of degradation or aggravation of the bed in the considered reach:

- 1. stable bed with negligible bed erosion/scour: hard rock or sedimentary bed material;
- 2. unstable bed composed of the same material transported by the flow, degrading or aggrading;
- 3. unstable bed composed of a different material as the one transported by the flow, degrading or aggrading.

The sites may thus be classified under nine main categories as shown in Figure 26 Classification of measurement sites for selecting the appropriate measurement. This information will be useful for analyzing comments in "Figure 37 Selection of instruments in sediment balance studies" (page 107).

Type of sediment load	Fine suspended load	High	Medium	Low
	Coarse suspended load	Low	Significant	High
	Bed load	Negligible	Limited	Significant
Type of channel	Stable bed, rock or poised	A	B	C
	Unstable bed, bed material suspended	D	E	F
	Unstable bed, bed material suspended but different	G	H	I

Figure 26 Classification of measurement sites for selecting the appropriate measurement

However, differentiation can also be made according to the flow regime, e.g. torrential or tranquil regime, or depending on the position in relation to particular reaches or structures, e.g. stations immediately upstream or downstream from reservoirs.

4.1.1.4.4 Some network considerations

Little has been done in terms of international standards for establishing sediment measurement networks. The routine networks, operated by governmental organizations are usually part of stream flow networks. Specific networks are often designed for particular projects and the duration of operation depends on the objectives, e.g. permanent stations in relation to monitoring reservoir sedimentation. However, designers of hydraulic structures such as water intakes for diversion, find themselves with a lack of data or with data of too short observation period. This situation has led to wrong assessment of the design data and failures in design and operation.

- 1. All primary stream flow stations should have sediment measured together with the flow, if feasible but not necessarily at the same location as the flow gauging section. They should all comprise at least simple suspended load measurement, but the need for more detailed suspended load, near bed load and bed load has to be evaluated for each individual site, depending on the sedimentological characteristics, geomorphic setting and data needs;
- 2. The network for sediment measurements other than routine suspended load gauging should consider the geomorphology and sedimentology of the stream catchment and course: changes in sediment load and associated possible sources, sudden changes in sediment transport capacity, changes in physical properties of the sediment (mainly size) etc.;
- 3. There are no specific requirements in terms of minimum stream basin area, but all the sediment sources of importance for establishing sediment balances should be included in the network;
- 4. Special requirements apply to specific situations as in deltas or estuaries, or in alluvial fans; they are too specific to be described here;
- 5. Sediment measurement networks need to be re-evaluated periodically, both their number and location. This upgrading has to be performed together with an evaluation of the stream flow data, but not only based on hydrological criteria;
- 6. It makes little sense to apply statistical and mathematical optimization techniques to the sediment measurement networks, mainly because of the complexity of the design and site selection criteria, e.g. the importance of geomorphology, but also because many stations are project oriented;
- 7. Sediment networks for both suspended load and bed load are expensive to equip and to operate; optimization is therefore a must, but it should rather be based on sound judgment and economic consideration (cost-effectiveness).

4.1.1.4.5 Proposed design method

Based on WMO document, we proposed to simplify the design approach as followed:

The optimum network would contain a sediment station at the mouth of each important river crossing international border. Sediment transport by rivers is a major problem in arid regions, particularly in those regions underlain by friable soils and in mountainous regions where, for engineering applications, the amount of sediment loads should be known.

Although the densities shown in “Table 14 Density for Surface water - Sediment stations” serve as guides in considering a basic network, but we must be forewarned that sediment-transport data are much more expensive to collect than other hydrological records. Consequently, great care must be exercised in selecting the number and location of sediment-transport stations. Emphasis should be placed on those areas where erosion is known to be severe. After a few years of experience, it may be desirable to discontinue sediment measurements at those stations where sediment transport no longer appears to be of importance. Sediment-transport data may be supplemented by surveys of sediment trapped in lakes or reservoirs.

Physiographic unit	Minimum density per station (area in km² per station)
Coastal	18 300
Interior plains	12 500
Small islands	2 000
Mountainous	6 700
Hilly/undulating	12 500
Polar / Arid	200 000

Table 14 Density for Surface water - Sediment stations

Based on these recommendations, we proposed to design the sediment network following different criteria shown in the " Figure 27 Surface water- Sediment network design" :

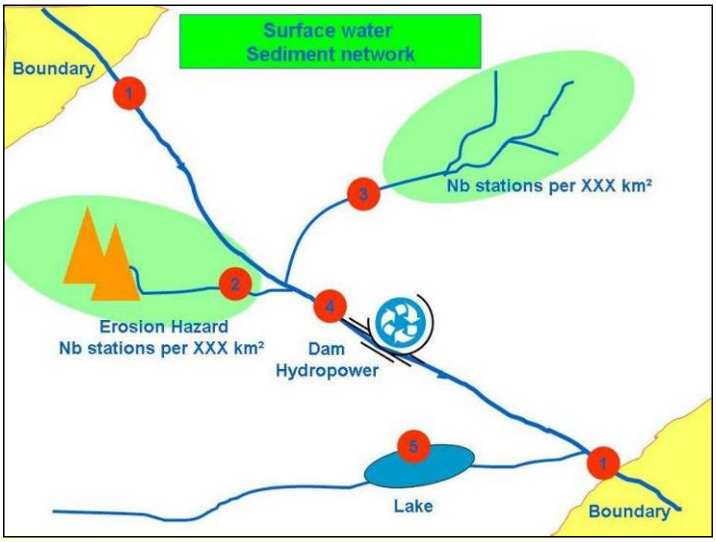


Figure 27 Surface water- Sediment network design

As possible, sediment stations must be connected to a hydrological station (discharge is needed for sediment transport analysis).

As the objectives of the network are sediment discharge and sediment transport (bed load), the measurement context will be sound different:

- to quantify the transport of sediment in the river system, it should be noted that peak concentrations of sediment do not necessarily correspond with times of peak flow;
- But sediment-transport rates are high during the floods;

If sediment network should be extended in the future to quality, then:

- for pollution from point sources, sampling should be done during low-flow periods, when pollution inputs are less diluted;
- When pollutants originate from diffuse sources such as runoff from the land of agricultural nutrients or pesticides, sampling must be focused on flood periods during which the pollutant is washed out of the soil.

N°	Location	Objectives	Measurement Frequency	Transmission Frequency
1	Closed to borders	Controlling the quantity of sediment at the entry and the exit of the national territory	Sampling at high frequency to create a rate curve. 2 times / Year during floods to control the validity or actualize the curve.	1 time / Year
2	Downstream a tributary	Controlling the quantity of sediment for an environmental survey	Sampling at high frequency to create a rate curve. Linked to flow gauging to control the validity or actualize the curve.	Linked to flow gauging
3	Downstream a tributary	Controlling the quantity of sediment for an environmental survey	Sampling at high frequency to create a rate curve. Linked to flow gauging to control the validity or actualize the curve.	Linked to flow gauging
4	In the dam reservoir	Controlling the quantity of sediment for an environmental survey	Sampling at high frequency to create a rate curve. Linked to quality survey by using echo sounding devices on boat to control the validity of the curve	Linked to quality survey
5	In the lake	Controlling the quantity of sediment for an environmental survey	Sampling at high frequency to create a rate curve. Linked to quality survey by using echo sounding devices on boat to control the validity of the curve	Linked to quality survey

Table 15 Sediment discharge and sedimentation – Measurement and data transmission requests

No aggregation rules have to be defining as frequency of acquisition is most of the time, linked to quality or flow measurement campaigns.

4.1.1.4.6 Design of the Surface water- Sediment network

Sediment stations have been selected by taking into account:

- Transboundary stations (Water level and Water quality),
- Water quality Trend stations,
- Few Water quality Baseline stations (little basin and up stream stations have been excluded),
- Few Water quality impact (some ones associated to main Water level stations)

	ABBAY	AWASH	BARO AKOBO	DENAKIL	GENALE DAWA
TOTAL	23	14	11	0	16

	MEREB	OMO GIBE	RIFT VALLY	TEKEZE	WABI SHEBELE	TOTAL
TOTAL	2	7	2	12	13	100

Table 16 Surface water sediment stations (density)

A detailed list of envisaged location stations can be found in annex n°2 to the present document. Results are produced in the map Figure 28 Proposed locations for Water surface Sediment stations.

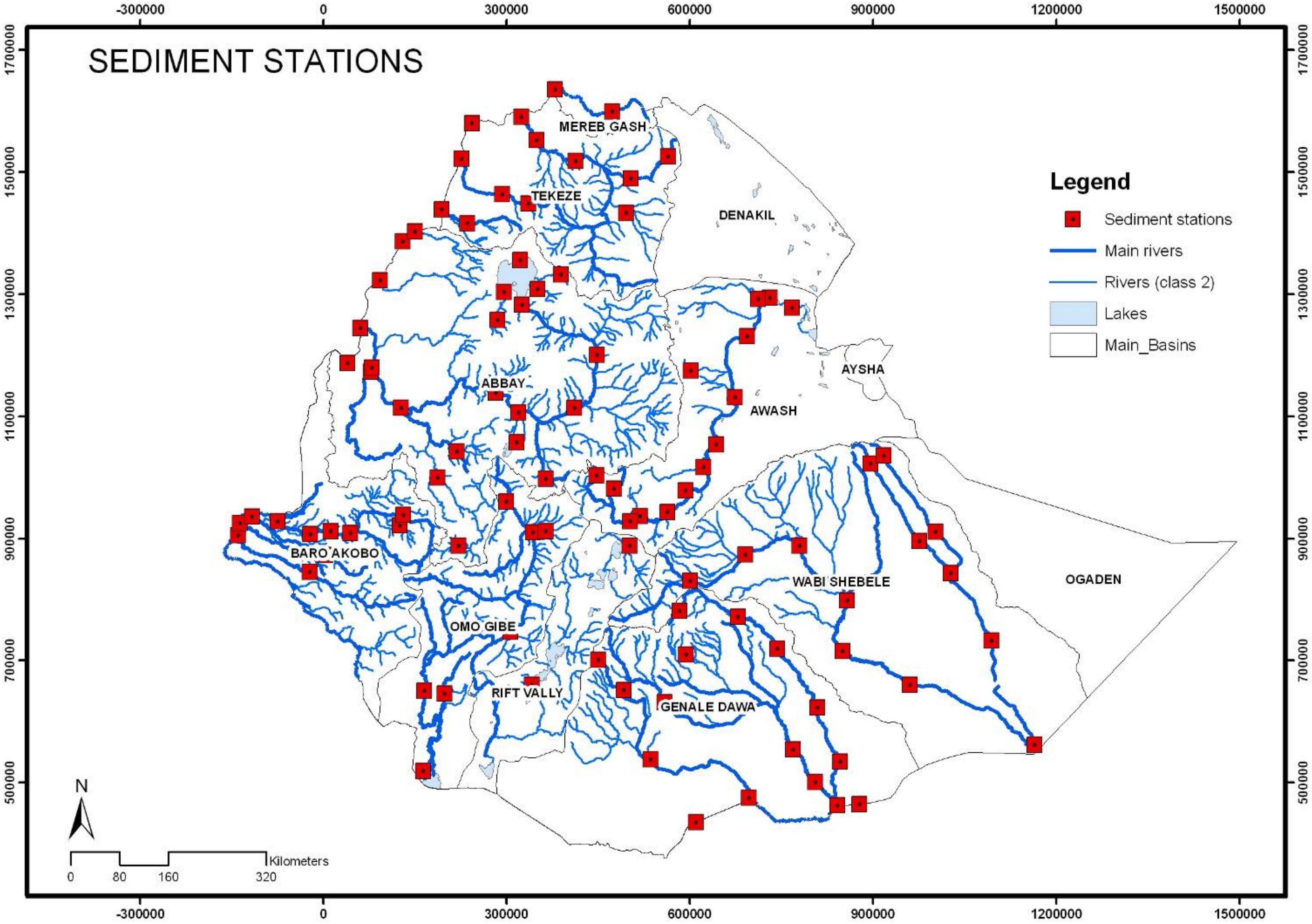


Figure 28 Proposed locations for Water surface Sediment stations

4.1.2 Groundwater

4.1.2.1 Quality network

Before designing the groundwater network, we want to remind its purpose. Classically three main reasons can be carried out for a groundwater quality monitoring:

- Determining the detailed water quality of a limited area in view of a future exploitation for irrigation, industrial or water-supply,
- Determining the extent of a local groundwater contamination and control its evolution with time,
- Determining the general groundwater quality at the scale of the country for an environmental preoccupation; health protection, prevent possible pollution and estimate the status and long term trends.

The aim of the MoWR seems to be close to the last point.

4.1.2.1.1 Criteria for selecting a station

The main quality of a station is to give a sample representative of the water of the aquifer tapped. In this condition, the best sites for sampling are springs producing a large flow and wells exploited at a big rate, as they have a significant area of influence in the aquifer. Another interest is their used for water supply, and then water quality is totally linked to the health of an important population.

A second family of station can be constituted by wells or boreholes used for water supply for villages, and by piezometers and irrigation bores. Priority will be done at those sites which are located in the upstream part of the aquifer in unconfined area where recharge of rain water and diffuse pollution by agricultural can exist. They can help to detect early water pollution flowing in the direction of large exploited area. Some of them can be situated downstream factories or towns. By using piezometers, we can be face to inconvenient of using non-operational piezometers, which impose in this case, special procedures for taking samples representative of the aquifer. Wells or boreholes are most of the time, located closed or in village, directly exploited with a simple and without any protection of the perimeter. In case of pollution shown by a sample analysis, it will be difficult to determine, if the pollution is limited to the well or is global for the aquifer. For this reason, the final choice of the wells must be done after field investigations.

To be selected for the network, sufficient information relative to the features of the well are necessary, for having a good interpretation of the analysis. Data required should at minimum, coordinates, altitude, diameter, geological, lithological profiles, and aquifer type (confined or not), water table elevation, soil occupation…. Undamaged boreholes or suspect casings, should be avoided.

4.1.2.1.2 Location of the stations (step1)

Face to the number of existing potential sites, already detailed in ENGDA software, we have to define the "size" of the network, in terms of number of stations, to have a homogeneous distribution of these stations at the country's scale.

As no well will be dug especially for the project, only station location, with access to the aquifer, will be selected. Only cold springs and existing wells or existing boreholes will be selected.

By using GIS, we have built a data model with the following hypothesis:

- As GIS don't have the precise location of the well fields for water supply, we have consider major cities with a population greater than 15 000 inhabitants. This ratio gives a rough estimation of abstraction flow around 10 liters per second (or 36 m^3 per hour, on the hypothesis of 60 liters per day per capita). With these assumptions, the GIS model results give 63 towns for all the Ethiopian territory;
- The available GIS data contain :
  - ✓ 104 springs location but without any rate discharge feature;
  - ✓ 201 boreholes location without any feature information;
  - ✓ The number of site location is probably widely below the reality which must be closed to several thousand;

The totality of these 368 potential stations is displayed in Figure 29, and seems to be homogenously distributed, except in Somalia which is few populated. As some stations are closed each other, reduction of the network size can be envisaged to, roughly, 200 stations without deterioration of the network density (Figure 30 Simplification of groundwater network (200 stations))

Linked to this, we propose to take into account the density of population (Table 17 Number of stations proposed by region) as it can be associated to deterioration of water quality, or to overexploited areas. This proposed network must be considered as a feasibility network and must be adapted to hydrological context.

Region	Population	Percentage of population /country	Distribution for 200 stations	Distribution for 368 stations
OTOMIA	27158471	36,7%	73	135
AMHARA	17214056	23,3%	46	85
SOUTHERN Region	15042531	20,4%	40	75
SOMALI Region	4439147	6,0%	12	22
TIGRAY	4314456	5,8%	12	22
ADDIS ABABA	2738248	3,7%	7	13
AFAR	1411092	1,9%	4	7
BENIS HANGUL - GUM	670847	0,9%	2	3
DIRE DAWA	342827	0,5%	1	2
GAMBELLA	306916	0,4%	1	2
HARARI	183344	0,2%	1	1
Special counting place	96570	0,1%	1	1
Total	**73918505**		**200**	**368**

Table 17 Number of stations proposed by region

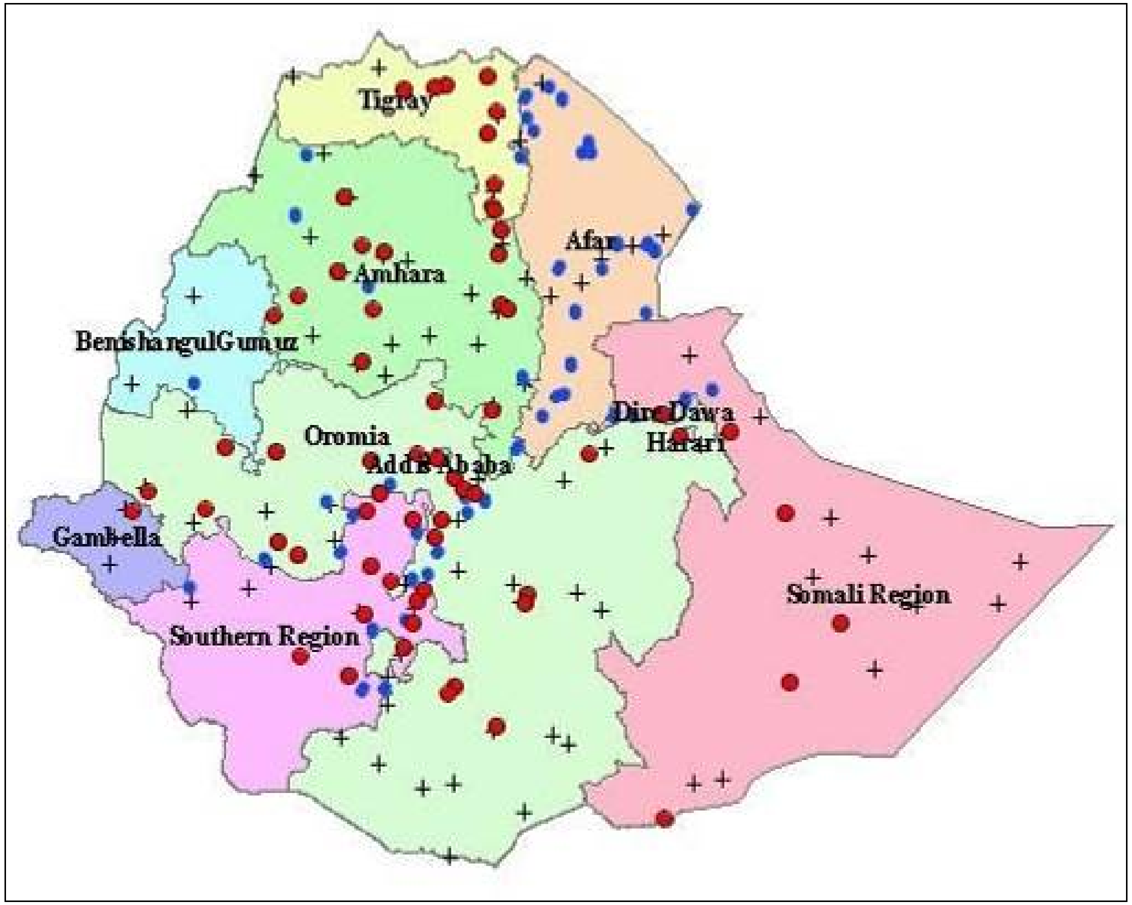


Figure 29 Potential groundwater stations

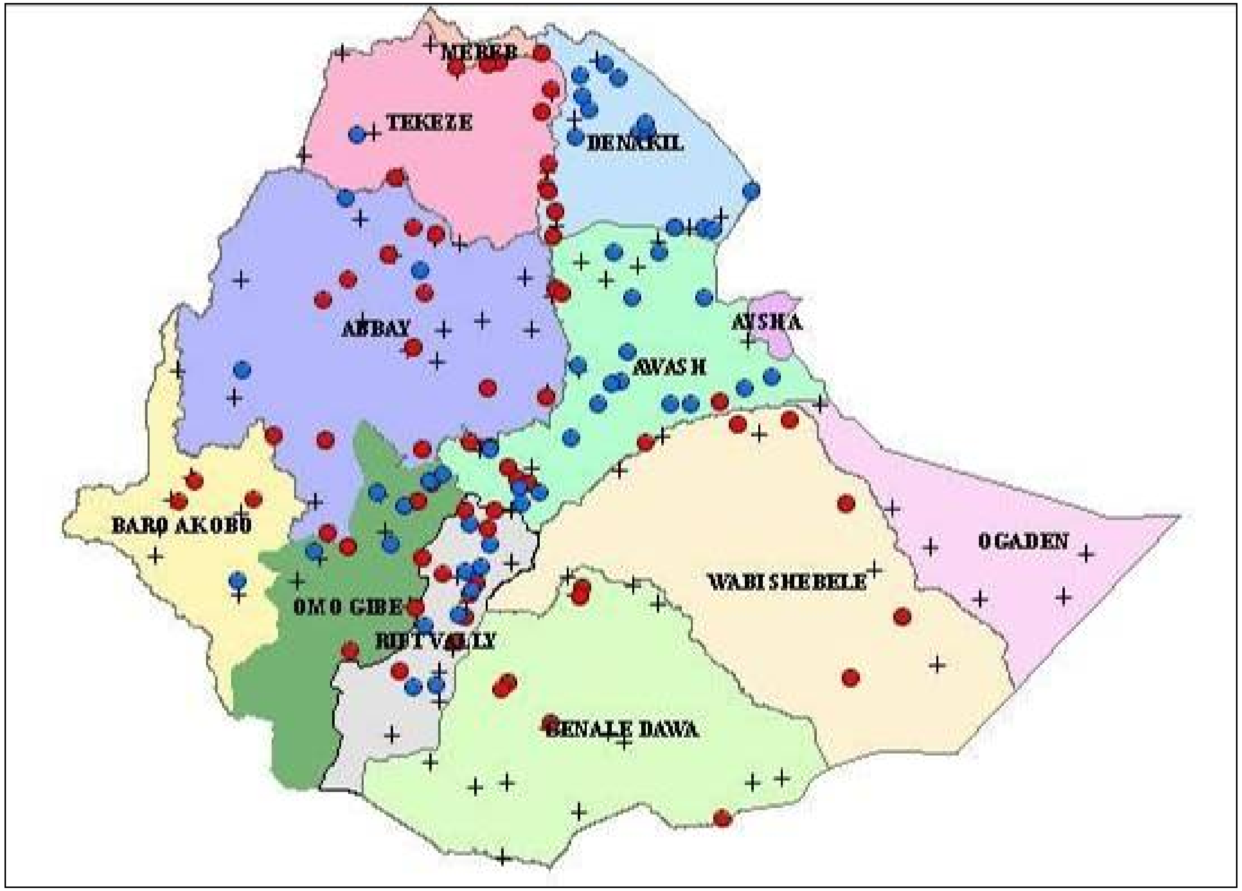


Figure 30 Simplification of groundwater network (200 stations)

4.1.2.2 Quantity network

The creation of a quantitative groundwater network must satisfy to objective triple:

- Appreciate the state of the resource in order to detect as soon as possible the aquifers which could be in the process of overexploitation,
- Improve knowledge on the water balance of the aquifers by giving the elements necessary to the study of the relation existing between precipitation and groundwater recharge,
- Anticipate the episodes of extreme dryness by the analysis of the curves of drying up.

Obtaining data necessary to these various objectives is extremely easy IF measurement of the water level evolution with time is available in wells or boreholes. This situation is not yet possible as no equipment is installed in-situ for this purpose.

CRITERIA FOR SELECTING A STATION

Contrary to the quality of water which can vary quickly in space because of the low capacity of dilution of groundwater, the state of the resource of an aquifer can be appreciated by a reduced number of piezometer because of the integrating effect produced by the porous media. It is also useful to specify that the future network is not intended to monitor well fields but to appreciate the general evolution of an aquifer. These two objectives are very different since a clogging of the boreholes or an increase of well field discharge lead to a fall of the water level in the sector close to the well field while at the scale of the aquifer the water table is not significantly affected by these phenomena. In a wellfield the level is mainly affected by abstraction conditions and not by climatic and general situation of the aquifer which is the aim of a water level network.

The level network will be consisted by not exploited wells distant from a few hundred meters of an important well field. They will be also far away from the significant rivers or lakes because these hydraulic units stabilize the levels of the water table and the measurement of the evolution of the water table in these zones is generally not very interesting.

As for water quality stations to be retained in the level network it is necessary to have a sufficient description of the design features of the well (coordinates, altitude, diameter, geological and lithological profiles, aquifer tapped, screen position).

4.1.2.3 Location of quality and quantity stations- Step 2

We suggest a work program to define precisely the groundwater network to be set up.

This program will describe in detail the operations to be undertaken for delivery:

- a map locates stations, with indication of the nature of the aquifers to be monitor;
- a detail chart for each Branch Office, or per river basin,
- an updating database (part of ENGDA) describing stations with their design features, location, diameter, depth, position of the screens, use of wells, nature of the aquifer tapped and types of analysis to be carried out,
- a precise estimation of the human and technical potential need to implement, create and manage the network;

All these elements will constitute a guideline to design en operational and cost – efficiently groundwater network. To achieve this goal and taking into account particularities of groundwater, only a local scale approach is suitable.

As many studies relative to the hydrogeology of Ethiopia are available, the detail design can be envisaged by going on through:

- a Bibliographical study of available reports and data to define a Preliminary Network,

- Field study must completed the desk study, and can permit to establish the Final Network,
- By building a database or, preferably, updating of the ENGDA, and creating a connection with the GIS to produce automatically maps of groundwater (quality and quantity).

BIBLIOGRAPHICAL STUDY : ESTABLISHMENT OF THE PRELIMINATY NETWORK,

As already mentioned many reports and data are available and offer the possibility to have precise information necessary to the design of a groundwater network. This detailed analysis must be done with the assistance of Ethiopian services (or Ethiopian company) which have a good knowledge of the hydrogeology of the country, to facilitate the data collection and data analysis. As more than 200 potential stations can be envisaged, the total duration for this part of works is estimated to 3 months and 4,5 man months of works.

FIELD STUDY AND DESIGN OF THE FINAL NETWORK

The first phase presented here before, will be complemented by a field study, to update and check the validity of information on site. Based on the network dimensions, the total duration for this part of works is estimated to 1 week per Regional Offices, roughly 3 months duration.

Preliminary Network obtained must be updated and checked on the field. It is necessary to visit all these potential sites to select the Final Network. The duration of this field operation is estimated at around 1 week by Branch Office (roughly 3 months) and 4 man months of works.

Every potential site will be updated in ENGDA, by indicating:

- Identification of the station,
- Location (X,Y,Z),
- Type (well, borehole, spring),
- Water uses destination (drinkage water supply, irrigation, industry…)
- Date of drilling,
- Equipment (diameter, total depth, screen location),
- Aquifer tapped type (alluvial, limestone, basalt, crystalline rock)
- Type of aquifer (confined, unconfined)
- Soil utilization (forest, agriculture, industrial, urbanized area)

ORGANISATION AND TIME OF THE STUDY

This project must associate international company to local Ethiopian hydrogeology Office. The tasks assignment will be as followed:

- For international company: general management of the study, coordination with the MoWR, and the Ethiopian Hydrogeology Office, redaction of the reports, adaptation works for database;
- Local Ethiopian hydrogeology Office will in charge to bibliography study, field operation, and participation to set-up of the Database.

The total time for this study is fixed to 9 months for a total amount of 10 man months.

4.1.2.4 Groundwater quality and quantity station priorities- Step 3

4.1.2.4.1 Monitoring type

Even it is not possible to make a real list of site location, some criteria can be defined, such as, groundwater monitoring classes which define the type of monitoring:

- ✓ A "basic monitoring" corresponding to a minimum for unexploited aquifers or good quality aquifers;
- ✓ A "periodic monitoring" for exploited aquifers potentially vulnerable to pollutions and droughts;
- ✓ A "reinforced monitoring" for over exploited aquifers, subject or not to pollutions;

4.1.2.4.2 Criteria for monitoring type selection

To make priority to this classification, criteria will take into account in four items:

- potential of the aquifer and strategic development of it (TH1);
- importance of uses and needs, and water usages (potable water, irrigation) provided by the resource and piezometric behaviour face to water intakes (picks, deficit) (TH2);
- vulnerability to pollution (TH3);
- pressure of potential pollution (TH4).

The first two items define the resource in terms of quantity. Their simultaneous consideration defines priority to instrumentation and determines the number of necessary measurement sites.

The other two issues concern the resource in terms of quality. The combination of these two criteria, assess the risk of pollution.

All four items will helpful to define priorities in the terms of number of points required, monitoring type which defines parameters to be measure and frequency of it.

POTENTIAL AND STRATEGIC DEVELOPMENT CRITERIA (TH1)

The potential and strategic groundwater importance can be assessed by using the following criteria:

- surface of the groundwater
- capacity of the water reserve
- renewal rate of the resource
- relationship with surface waters
- status free/captive
- productivity average (based on operation books or estimation)
- existence or not of a substitution resource

WATER USAGES CRITERIA & PIEZOMETRIC CRITERIA (TH2)

Can be identified the following criteria:

- annual water volume intakes
- ratio (%) of water usages (drinkable water, irrigation, industry)
- envisaged evolution of water volume intakes
- reaction to intakes: water level evolution
- potential "artificial" recharge area
- sensitivity to droughts

The impact of water intakes can be evaluated by analysis of piezometric timestamp archive.

VULNERABILITY OF THE RESOURCE (TH3)

We have to distinguish the vulnerability of the groundwater or "intrinsic" vulnerability, and the vulnerability of drilling equipments (like pumps) used for water intakes in the aquifer.

In fact, "intrinsic vulnerability" considers the capacity (good, fair, poor) of the aquifer to be protected from pollutions. It concerns only physical factors which influence pollutant evolution to the aquifer (and not inside the aquifer). The "intrinsic vulnerability" is independent of the pollutant type, and considers only (static or pseudo static) physical factors without any change at short term. Note that vegetation (forest…), culture type are not concerned in this list, as they can change rapidly (seasons..).

In the intrinsic vulnerability assessment, may be retained the following criteria:

- The permeability of non-saturated zone (characterized by the lithology), a permeability scale can be built on lithology basis. Karsts aquifers can be then considered highly vulnerable;
- The thickness of the non-saturated zone can postponed the pollution intrusion in the groundwater, but it can also have an action to minimize or eliminate the contaminant. Indeed, the transit time to cross the non-saturated zone can permit chemical or biological processes which can degraded the pollutant. More longer is the time transit, less important is the "intrinsic vulnerability";
- The water retention capacity of soil, which must be synthesized by a simple descriptor provide by soil maps at regional scale. This descriptor will be linked to classes of soil (such as dominant clay stone, sandy…).

POLLUTION PRESSURE (TH4)

Polluting pressure will be appreciated by analyzing the occupation of soil, by using following criteria:

- importance of the agricultural surface
- importance of the urbanized zone surface
- importance of the industry
- importance of domestic pollution (in rural zone)

RISKS OF POLLUTION

The risk of pollution is evaluated by crossing criteria relative to vulnerability and criteria concerning the pollution pressure. This evaluation must also require the issue of risk. By example, if the concerned aquifer is not exploitable due to its poor productivity potential, or to its poor quality, then the risk will be considered as LOW level by the evaluation method, but the vulnerability of the aquifer will be unchanged.

4.1.2.4.3 Criteria evaluation rules

Allow the criteria for the first two themes (TH1 and TH2) prioritize groundwater to the objective of monitoring of levels. It gets a first level of classification.

The criteria for the themes "vulnerability" and "polluting pressure" are used to prioritize groundwater face to a risk of pollution. This second level of classification, combined with the first, lets you therefore prioritize groundwater for the objective of the water quality monitoring.

For making priority, a simple "arithmetic" method based on the calculation of a comprehensive note will be assigned to each criterion, and each criterion will receive a "weight" in the evaluation.

NOTATION OF CRITERION

In a first step, each successful test will be a subdivision in class of "values" such as, for example:

Test	Value of classes
Potential and strategic development of the aquifer	Poor
	Fair
	High
Water intakes	Minor
	Means
	Important
Resistance to drought	Poor
	Fair
	High

If necessary, the subdivision may be refined (5 subclasses for example), but the level of detail in defining groundwater classification must be compliant with the scale and with the knowledge relative to these groundwater.

Some criteria can be also a numerical subdivision (0-10%, 10%-25%...) using available data permit it.

In a second step, a note will be assigned to each subdivision. In the case of a subdivision into three classes, the possible notes will be 1, 2 or 3. This note will be particularly high for a sensitive aquifer, or an aquifer with high economic importance. An important note will correspond to a high level of monitoring, for example, an aquifer characterized by a low resistance to the drought, important water intakes and limited potential reserves).

4.1.2.4.4 Proposed priority groundwater stations

As most of data are not available to make a list of stations (classed by priority), we suggest to select groundwater stations closed to urban zones. The priority will be based on the number of inhabitants.

In selected urban zones, if well fields are already equipped with piezometers (for drinkable water purpose for example), these data will be collected by staff in charge of well operations, and transmitted to MoWR by email.

4.2 DATA COLLECTION

4.2.1 Water level data collection

4.2.1.1 Surface water- gauging stations

The measurement of water level or stage at a gauging station is perhaps the most fundamental in hydrology. Field practice and frequency of observation should match with the data needs and the available instrumentation. The greatest frequency of observation is required when the level (and discharge) is changing rapidly in response to rainfall, especially during the monsoon season and on small catchments.

Manual observations by staff gauge will remain as the sole means of observation at some stations for many years. They will also continue to be used at all stations to check the operation of recording equipment at intervals, as a back-up in the event of instrument failure and in conjunction with discharge measurements for stage-discharge determination.

Operation will consider:

- Staff gauge stations
- Stations with autographic chart recorder
- Stations with digital water level recorders

4.2.1.1.1 Staff gauges

The gauge observer will read the water level at an external staff gauge located directly in the river, and record to the nearest 1 cm where the water has little surface fluctuation. Where the water level is unstable due to wind action or turbulence, the observer will assess the mean level by noting the level fluctuation over a period of approximately 30 seconds and take the mean (average) of the normal range. An internal staff gauge situated in a stilling well will not normally be used as the primary water level measurement. Observation will be made by making the closest possible approach to the gauge consistent with safety. Where the staff gauge is likely to become too distant for accurate gauge readings during rising flood levels, a simple pair of binoculars may be provided.

The frequency of observation of staff gauges and the period over which the observational frequency is to be applied, will be specified for a given station and observations will be recorded on a standard form. Examples of the standard forms to be used for daily, twice, trice daily and hourly readings are presented in "Figure 31 example of a Water level station field record book".

During the flood crisis where the flow is high and variable, hourly staff gauge observations are made over the full 24 hours period where the staff gauge is the sole means of level measurement.

The forms may also be used to record the maximum and minimum water level during the day in addition to hourly levels, is such additional data is available. In rapidly changing flows, the maximum level may exceed the highest recorded hourly level, when it occurs between the hourly observations. Similarly, the minimum level may be lower than the lowest hourly level.

The gauge reader is required to maintain good time keeping and the hourly observation will not fall more than 5 minutes before or after the hourly observation time.

The observer will note on the form whether the gauge is the only gauge, the main gauge, or a supplementary gauge, or gauges, for assessing surface water slope. A separate form will be used for each supplementary gauge in use. It is important that each gauge is clearly identified on the form. For supplementary gauges the observer will note whether the gauge is upstream or downstream from the main gauge. Where supplementary gauges exist, the upstream gauge will be read first and the downstream gauge as soon thereafter as is consistent with safety.

During periods of low flow or where the station is equipped with a reliable automatic or digital method of recording, the observer will take readings three times daily at 0800, 1300 and 1800 hours and record on the standard form covering a period of one month per form. Where an internal gauge exists in a stilling well it will be read once daily at 0800 and recorded.

When the gauge observer reads the gauge at other, non-standard times, he must ensure that he records the actual time of reading.

When the gauge observer is unable to visit the station for sickness or other reason he will in no instance attempt to estimate or interpolate the missing value(s) but will leave the space blank or note "M" and record in "Remarks" the reason for the missing record.

The observer will ensure that there is a direct connection between the flowing water surface and the gauge. After flood siltation he will, if necessary, remove sandbars or dig a trench from the gauge to free water. A shovel will be provided for this purpose. The channel to the gauges may require renewal on a daily basis.

The observer will note in "Remarks" all those occurrences which may influence the level as observed at the gauges and especially those which may affect the level-discharge relationship. The time/date and location of occurrences will be noted. The following occurrences in particular will be noted:

- damage or destruction of gauges due to flood or other cause
- scouring and lowering of the river bed level either at the gauges or at the control site
- construction of bunds downstream to raise water level for abstraction or diversion
- extraction of sand or gravel from the river channel
- blockage or partial blockage of the channel by floating or other debris in flood
- significant weed growth in the channel or on the weir and its subsequent removal.

The observer will record the level at which flow ceases and the pool of water at the gauges becomes static.

Where the river level falls below the level of the lowest gauge but flow continues, for example due to scouring of the bed at the station, the observer will attempt to continue the observations. In such occasions, the observer will measure downward from the datum of the gauges and record it as a negative stage i.e. he will measure the distance from the zero on the gauge to the water surface. For example if the distance from the gauge zero to the water surface is 0,15 m, then the gauge reading should be recorded as -0,15 m. As soon as possible, the engineer in charge will re-survey the station and reinstall the gauges with a new datum, ensuring that survey details and the change in datum are fully documented in the Station Record.

4.2.1.1.2 Autographic chart recorder (float system)

To ensure efficient and continuous operation of the autographic chart recorder, it is necessary that the observer checks daily the condition of the recorder and installation and compares levels shown on the recorder with those on the reference staff gauge. This regular check is required to minimize malfunctioning for a period of time.

The following general routine is to be applied on a daily basis:

1. Read the outside reference gauge, cleaning if necessary.
2. Read the inside reference gauge if one is installed
3. Read the indicated level on the chart and compare with the above i.e. steps 1 & 2. If the readings do not agree, find the cause and remedy it.
4. Check that the clock is running and read the time indicated by the pen on the chart.
5. Enter all readings of water level, recorder time and clock/watch time on the chart. For this purpose the operator is provided with a reliable watch.

6. Mark the chart with a short vertical line by raising the float wire.
7. Remove the stylus (pen) from the chart.
8. Remove the chart drum from the recorder.
9. Remove the chart from the drum by cutting cleanly with a sharp blade. Do not cut at the joint, as it is essential to be able to examine the join to determine any error.
10. Place the new chart tightly on the drum, making sure that it fits properly on the rim and that it matches on the joining edges.
11. Rewind the clock.
12. Check the stylus (pen) assembly to ensure that it is working properly and recharge with ink if necessary.
13. Replace the chart drum on the recorder.
14. Check the float and counterweight assembly and clean the float if necessary.
15. Clean and oil the recorder mechanism according to the manufacturer's instructions.
16. Rotate the drum anticlockwise to eliminate backlash.
17. Reset the stylus on the chart at the correct time and level.
18. Enter the readings of water level and time on the check form or on the new chart.
19. Before leaving the station check that the instrument is working properly.
20. Lock the lid or door of the recorder housing.

4.2.1.1.3 Digital water level recorders

Digital water level recorders (using DCPs) take a variety of forms but have in common the ability to measure and register the water level at a specified interval in digital storage on a data logger. The sensor may take the form of a float-operated shaft encoder, a pressure transducer, an ultrasonic in air sensor or a radar sensor. DCP for water level measurement also take several forms, those with separate removable memory, those with integral memory for which a standard portable PC computer is used to set-up and download data, and those with integral memory but with proprietary retrieval device.

The methods of setting up and checking DCP for water level recording (DWLR) depend upon the type of logger and sensor and on software specific to a logger type. Visual checking of the performance of the DWLR is possible if an on-site display is incorporated into the DCP. Routine data retrieval and checking involves following steps:

1. Read the reference staff gauge.
2. Plug in the computer or data retrieval device to the DCP and check the current level.
3. Check that the DCP clock is within acceptable time accuracy.
4. Enter all current readings of water level, DCP time and clock time in the Station Record Book and compare with previous performance record.
5. Download the DCP data (even data can be transmitted by satellite), either the full stored contents or the data since last download, as required.
6. Check exchangeable battery power sources and replace if below the recommended voltage, paying due attention to the time period, which will elapse before the next service visit.
7. If DCP level and reference level disagree, depending on the level of disagreement, three categories of associated action may be applied
   - ✓ Adjust DCP to reference level
   - ✓ Investigate potential faults including stilling well blockage if one is installed. Remedy if possible and adjust DCP.
   - ✓ If no problem is identified and disagreement persists, remove DCP and/or sensor and replace.

1. If DCP and clock time disagree, depending on the level of disagreement, three categories of associated action may be applied
   - ✓ Do not adjust (will be done automatically by the control center)
   - ✓ Adjust DCP to clock time
   - ✓ Remove DCP and replace
1. Restart DCP if necessary (most modern DCP do not need to be restarted)

4.2.1.1.4 Water level station field record book examples

Station field record book

Basin		River		Station name		Station n°	

Date	Time	Staff gauge level	AWLR /DWLR level	Remarks (including damage, adjustment, replacement of staff gauges or equipment, stlling well malfunction, erosion and scouring, construction of bunds, sand extraction, debris blockage etc)

Figure 31 example of a Water level station field record book

Station log book

Basin		River		Station name		Station n°	

Gauges	Primary (PG)	Secondary (SG1)	Secondary (SG2)	Secondary (SG3)
Gauges zero				

Equipment	Yes/No	Type	Factory name	Serial number	Installation date
Water level recorder		AWRL / Autographic Water level recorder DWRL/ Digital Water level recorder			
Current meter					
Cableways/bridge outfits					
Other					

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Date	Time	PG level	AWLR/ DWLR level	Stilling well level	Level Diff. (3) - (4)	Level Diff. (3) - (5)	AWLR/ DWLR time	Time diff. (2) - (8)	SG1 level	SG2 level	SG3 level	Measured flow (fm)	Time start fm	Time finish fm	Conditions (river and weather)	Actions taken	Remarks	Signature

Figure 32 example of a Water level station log book

4.2.1.2 Ground water level

For economic reasons and to have data of quality measurement of the level can be carried out with the means of automatic probes placed inside the wells. The current material is extremely powerful and reliable. It requires no maintenance intervention on the field since the probes have an autonomy which largely exceeds the year with an automatic measurement of time level at the selected periodicity.

The recovery of the data can be done with a portable computer connected at the probe. Suitable software makes it possible to treat and visualize the gathered data.

The recorders have very significant storage capacities. One can thus adopt a measure of level every 4 hours or 6 per day what makes it possible to appreciate the conditions of recharge of the aquifers in the sectors where there is a rain gauge. Concerning the data-gathering on the field we propose a periodicity of 4 or 6 months what makes it possible to establish a state of the resources for rainy or dry season. Downloading the data collected by the logger is done via infrared interface to a notebook. For the occasion of the data-gathering it is necessary to compare the level measured with a manual electric gauge and the value indicated by the logger.

An automatic transmission can also be proposed as we will see hereafter.

As for the data of quality measurements will be criticized and developed by graphic treatments before being introduced into the Database.

4.2.2 Water quality data collection

4.2.2.1 Introduction

The main objectives for water quality (surface and ground water) monitoring are identified as:

- monitoring for establishing baseline water quality
- observing trend in water quality changes
- calculation of flux of water constituents of interest
- surveillance for irrigation use
- control and management of water pollution (for groundwater only)

The document is meant to be used as a ready reference by the field staff, water quality, laboratory personnel and managers of the water quality monitoring programs.

4.2.2.2 Frequency and Parameters

4.2.2.2.1 Groundwater

Groundwater quality can be defined by a range of parameters described by concentration and state (dissolved or particulate) of some organic and inorganic material present in water with certain physical characteristics of the water. Some of theses parameters have to be measured on the field and the others at the laboratory with more efficient material.

Water quality depends on the composition of the recharge water, the interaction between the soils, the rocks reservoir and residence time in the aquifer. At these naturals conditions we have to add possible influence of human activities (industrial, agricultural or sewage). For all these factors groundwater composition varies widely at the scale of a large country as Ethiopia where we find many types of aquifers (karstics, volcanics, alluvial) Water composition can also differ a little bit with hydrological cycles particularly in karstics area where infiltration is fast. In fact if we exclude the accidental addition of pollutants water composition is normally stabilized. Just human activities with chronic pollution or climatic change can introduce year to year a small trend. For this reason long historic data is necessary to detect this type of evolution.

More than 90% of the dissolved solids in groundwater can be attributed to eight ions: Na, Ca, K, Mg, $S0_4$, Cl, HCO_3, CO_3. These ions are usually present in concentration greater than 1 mg/L. Silica SiO_2, a nonionic species, is also typically present with more than 1 mg/L. To know proportion of Bicarbonate and Carbonate it is necessary to measure at the time the sample is collected together with pH and temperature.

Other naturally occurring ions may be present in amounts of 0.1 mg/L to 10 or more mg/L include Iron, Nitrate, Phosphate, Fluoride

The program suggested includes 4 modules whose parameters can be or not analyzed in routine. It comprises a basic routine analysis program **(BRA)** which is the normal programme used for a comprehensive knowledge of water quality. It will be applied to all the stations of the network. The complementary modules containing significant number of products corresponding to different types of pollution will be added if necessary and research will be adapted to the local context (factories, agriculture, mine).

We describe successively:

- Basic Routine Analysis **(BRA)**
- Minerals micro-pollutants **(MMP)**
- Organics micro-pollutants **(OMP)**
- Microbiology **(MB)**

Basic Routine Analyses **(BRA)** contain:

In-situ measurements:	At the laboratory:	
Temperature of water	Calcium (Ca^{2+})	Nitrate (NO_3^-)
pH, dissolved oxygen	Magnesium (Mg^{2+})	Chloride (Cl^-)
Electrical Conductivity	Sodium (Na^+)	Bicarbonate (HCO_3^-)
Alkalinity	Potassium (K^+)	Carbonate (CO_3^{2-})
	Silica (SiO_2)	Iron Total
	Sulphate ($S0_4^{2-}$)	Fluoride (F^-)
	TDS (evaporation)	

Minerals micro-pollutants **(MMP):**

- Total Chromium (Cr)
- Nickel (Ni)
- Mercury (Hg)
- Zinc (Zn)
- Copper (Cu)
- Arsenic (As)
- Lead (Pb)
- Cadmium (Cd)
- Selenium (Se)

Organics micro-pollutants **(OMP):**

- Organochlored (lindane, metalochlor)
- Organoazoted (Atrazine, Simazine)
- Organo halogenated volatils (tetrachlorethylen, trichloroethylene, chloroform, tetrachlorure de carbon, trichlorethane)

Microbiology **(MB):**

The discharge of wastes may contain pathogenic (disease causing) organism and may be hazardous if polluted water is used as drinking water or food preparation. Faecal contamination is detected by microbiological analysis. Total coliform is not necessary sign of polluted water but faecal coliform (Escherichia Coli) proof of faecal contamination.

SAMPLING PERIODICITY

The program of sampling to be set up must produce a correct description of the quality of groundwater through the country while taking account the economic constraints and organisational. The theoretical frequency of sampling of a station depends on various factors:

- Natural variations related to climatology,
- Probability of an entropic influence,
- Hydrochemistry variations observed in the past on this station.

The strict respect of these criteria would lead to a frequency of sampling which would vary from one station to another. In practice and for economic reasons, and without changing the results obtained, the periodicity of measurements is identical for all the stations. This option is retained in the European countries with two annual measurements, one in wet period and the other in dry period.

We suggest the same periodicity at dates adapted at the local climatology to obtain one sample in dry season and the other just after the rainy season. All the analyses will be of type **BRA**. The interpretation of the whole of the results obtained will permit to maintain this periodicity and the type of analysis. In case of anomaly complementary analysis corresponding at the modules proposed must be done.

4.2.2.2.2 Surface Water

Since not much is known about the present water quality status at various stations, to start with, all stations will be a combination of baseline and trend stations.

Samples will be collected every two months. This will generate six samples from perennial rivers and 3-4 samples from seasonal rivers, every year. After data are collected for three years, the stations will be classified either as baseline, trend or flux station. Those stations, where there is no influence of human activity on water quality, will be reclassified as baseline stations. Others will remain as trend stations.

If a station is classified as a baseline station, it will be monitored, after every three years, for one year every two months.

If a station is classified as trend station, it will continue to be monitored but with an increased frequency of once every month.

Stations will be classified as flux stations where it is considered necessary to measure the mass of any substance carried by the flow. The frequency of sampling at such stations and analyses of constituents of interest may be increased to 12 or 24 times per year. Measurement of discharge at such stations is necessary.

The recommended parameters for analysis are given in “Figure 33 Parameters of analysis for water surface samples”.

Other inorganics, metals, organics and biological parameters will be determined as part of special survey programs.

The survey programs may include some of the trend stations where there is a need for determination of any of these groups of parameters.

The survey programs will ordinarily be of one year duration. The sampling frequency may be the same as that for trend stations.

Special arrangements for sampling and transport of the samples would be necessary for the survey programs and microbiological samples.

Parameter Group	Initially	Baseline	Trend
General	Temp, EC, pH, DO, TDS	Temp, EC, pH, DO, TDS	Temp, EC, pH, DO
Nutrients	NH_3^-N, NO_2 + NO_3,total P	NH_3^-N, NO_2 + NO_3,total P	NH_3^-N, NO_2 + NO_3,total P
Organic matter	BOD, COD	BOD, COD	BOD, COD
Major Ions	Ca^{++}, Mg^{++}, K^+, Na^+, CO_3^{--}, HCO_3^-, Cl^-, SO_4^-	Ca^{++}, Mg^{++}, K^+, Na^+, CO_3^{--}, HCO_3^-, Cl^-, SO_4^-	Cl^-,
Other inorganics	None	None	None
Metals	None	None	None
Organics	None	None	None
Microbiological	Total coliforms	None	Total and Faecal coliforms
Biological	None	None	None

Figure 33 Parameters of analysis for water surface samples

4.2.2.3 Sample Collection

Some analyses must be carried out in the field using special devices. It is the case for temperature, pH, conductivity, dissolved oxygen and alkalinity very sensitive with time. Others parameters are not affected by time or can be chemically preserved and analysed later at the laboratory.

For sensitive parameters measurement must be done immediately after sampling:

Temperature of water, is obtained with an electronic meter,

pH, with a portable electronic ph meter with a probe kept immersed in distilled water,

Conductivity measures the ability of water to conduct electric current and depends on the concentration of ions in solution. The unit is the millisiemens per meter (1 mS m^{-1} = 10 micro S cm^{-1}). The measurement should be made immediately because there is interaction with air and the conductivity change with time. Conductivity is also dependent of temperature but ph meter are equipped of an automatic correction and gives the value for 20°C by this way it is possible to make comparison of different waters. The ph meter must be calibrated with standard solutions furnished by the constructor. In case of contamination of the probe with waste water or oil it must be cleaned with alcohol and rinsed with distilled water.

Dissolved oxygen concentration depends on the physical, chemical and biochemical activities in the aquifer. The measure is done on the field by a specific electronic probe it is necessary that samples must be taken carefully with no air bubbles altering the dissolved oxygen concentration.

Alkalinity. It is preferable to carry out the analysis by titrating the sample with acid on the field. It can however be carried out later at the laboratory if the sample is safe from air by filling the bottle completely.

The samples volumes required for chemical analyses depends largely of the methods used by the laboratory. It is thus necessary to clarify this point with him. For an analyses type **BRA** a volume of 1liter is necessary, for microbiological analysis 1/3 liter.

For wells or piezometers without equipment we must use a small electric portable pump to take sample after extraction of 2 times de casing volume.

4.2.2.3.1 General recommendations

- At least one day before sampling, make sure that all the arrangements are made as per the check list given hereafter.
- Make sure that you know how to reach sampling site(s). Take help of location map for the site which shows the sample collection point with respect to prominent landmarks in the area. In case there is any deviation in the collection point, record it on the sample identification form giving reason.
- Rinse the sample container three times with the sample before it is filled.
- Leave a small air space in the bottle to allow mixing of sample at the time of analysis.
- Label the sample container properly, preferably by attaching an appropriately inscribed tag or label. The sample code and the sampling date should be clearly marked on the sample container or the tag.
- Complete the sample identification forms for each sample, Figures 1 and 2 for ground and surface water, respectively.
- The sample identification form should be filled for each sampling occasion at a monitoring station. Note that if more than one bottle is filled at a site, this is to be registered on the same form.
- Sample identification forms should all be kept in a master file at the level II or II+ laboratory where the sample is analyzed.

4.2.2.3.2 Groundwater

- Samples for groundwater quality monitoring would be collected from one of the following three types of wells:
    - ✓ Open dug wells in use for domestic or irrigation water supply,
    - ✓ Tube wells fitted with a hand pump or a power-driven pump for domestic water supply or irrigation
    - ✓ Piezometers, purpose-built for recording of water level.
- Open dug wells, which are not in use or have been abandoned, will not be considered as water quality monitoring station. However, such wells could be considered for water level monitoring.
- Use a weighted sample bottle to collect sample from an open well about 30 cm below the surface of the water. Do not use a plastic bucket, which is likely to skim the surface layer only.
- Samples from the production tube wells will be collected after running the well for about 5 minutes.
- Non-production piezometers should be purged using a submersible pump. The purged water volume should equal 4 to 5 times the standing water volume, before sample is collected.

- For bacteriological samples, when collected from tubewells/hand pump, the spout/outlet of the pump should be sterilized under flame by spirit lamp before collection of sample in container.

4.2.2.3.3 Surface Water

- Samples will be collected from well-mixed section of the river (main stream) 30 cm below the water surface using a weighted bottle or DO sampler.
- Samples from reservoir sites will be collected from the outgoing canal, power channel or water intake structure, in case water is pumped. When there is no discharge in the canal, sample will be collected from the upstream side of the regulator structure, directly from the reservoir.
- DO is determined in a sample collected in a DO bottle using a DO sampler. The DO in the sample must be fixed immediately after collection, using chemical reagents. DO concentration can then be determined either in the field or later, in a level I or level II laboratory.

4.2.2.3.4 Sample Containers, Preservation and Transport

Field operation of sampling must be coordinated with the laboratory analysis to reduce the period between sampling and the analysis. Each sample bottle must be identified with the following information:

Ministry of Water Resources

Groundwater Quality Network: *Station identification: DM 17*

Date/time sampling: *12 June 20010 – 14h20*

Method of sampling: Pumped (Well or borehole) or direct sampling in the spring or river

Field measurements: *Temp °C: 19*
pH (U pH): 7,1
Conductivity (Micro S/cm 20°C) : 868
Dissolved oxygen (mg/L): 2.6
Alkalinity (mg/L of Ca CO_3): 125

Name of operators: xxxxxl

The table below specifies the theoretical time in which the analyses must be done. It appears that the most fragile parameters are Nitrates, Nitrites and Alkalinity which must be analyzed within 48 hours following sampling. In fact, without harming significantly the quality of the analyze it is possible to adopt more significant times of about 6 days.

This problem of time remains posed for the microbiological analyses which must be imperatively made within 24 h. One can plan to use the local laboratories when it is possible.

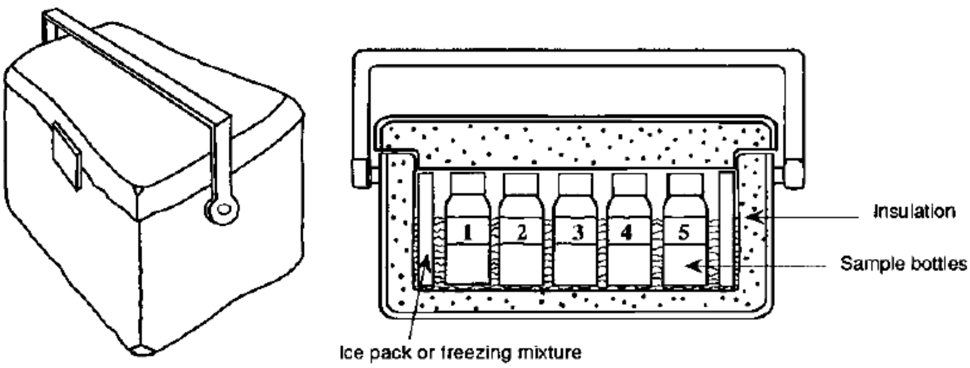
Parameter	Bottle	Preservative	Maximum storage time
Calcium (Ca^{2+})	Polyethylene	Cool 8°C<	6 days
Magnesium (Mg^{2+})			
Sodium (Na^{+})			
Potassium (K+)			
Sulphate (SO_4^{2-})			
Chloride (Cl^{-})			
Alkalinity			(48h) 6 days
Nitrate (NO_3^{-})			
Nitrite (NO_2^{-})			
Silica			6 days
Fluoride			
Arsenic			6 months
Bore			

Table 18 Maximum permissible storage time

So, samples should be transported to concerned laboratory (level II or II+) as soon as possible, preferably within 48 hours.

- Analysis for coliforms should be started within 24 h of collection of sample. If time is exceeded, it should be recorded with the result.
- Samples containing microgram/L metal level should be stored at 4oC and analysed as soon as possible. If the concentration is of mg/L level, it can be stored for up to 6 months, except mercury, for which the limit is 5 weeks.
- Discard samples only after primary validation of data.

Samples should be placed in an insulated plastic box with an ice pack for the transport at the Branch Office where they will be placed in a refrigerator before their final transfer at the laboratory.



Use the following type of containers and preservation:

Analysis	Container	Preservation
General	Glass, PE	None
COD, NH_3, NO_2^-, NO_3	Glass, PE	H_2SO_4, pH<2
P	Glass	None
DO	BOD bottle	DO fixing chemicals
BOD	Glass, PE	4°C, dark
Coliform	Glass, PE, Sterilized	4°C, dark
Heavy metals	Glass, PE	HNO_3, pH<2
Pesticides	Glass, Teflon	4°C, dark

Sample code											
Observer				Regional office				Project			
Date				Time				Station code			
Source of sample : () Open dug well				() Hand pump		() Tube well well		() Piezometer			
Parameter code	Container				Preservation				Treatment		
	Glass	PVC	PE	Teflon	None	Cool	Acid	Other	None	Decant	Filter
(1) Gen											
(2) Bact											
(3) BOD											
(4) COD, NH_3, TO_xN											
(5) H Metals											
(6) Tr Organics											

Field determination					
Temp: °C	pH	EC	µmho/cm	DO	Mg/L
Odour code	(1) Odour free	(6) Septic	Colour Code	(1) Light brown	(6) Dark green
	(2) Rotten eggs	(7) Aromatic		(2) Brown	(7) Clear
	(3) Burnt sugar	(8) Chlorinous		(3) Dark brown	(8) Other
	(4) Soapy	(9) Alcoholic		(4) Light green	(specify)
	(5) Fishy	(10) Unpleasant		(5) Green	

- If well is purged

Office well data			
Diameter	Φ		cm
Depth	D		m
Static water level (avg)	SWL		m
Water column (D-SWL)	H		m
Initial volume well	V		L
Project pump discharge	PQ		L/s
Project time for purging (V/PQ)	PT		minutes
Field Flow Measurement			
Static water level on arrival	SWL		m
Actual pump setting			m
Purging duration			minutes
Pump discharge before sampling	Q		L/min
Pump discharge after sampling	Q		L/min
Volume purged	V		L
Dynamic water level	DWL		m
Field Chemical Measurement			
Time at start of sampling started	T(°C)	EC(µmho/cm)	pH
+10 minutes			
+20 minutes			
+30 minutes			
+40 minutes			

Figure 34 Sample identification form for groundwater samples

Sample code		
Observer	Regional office	Project
Date	Time	Station code

Source of sample : () Open dug well () Hand pump () Tube well well () Piezometer

Parameter code	Container				Preservation				Treatment		
	Glass	PVC	PE	Teflon	None	Cool	Acid	Other	None	Decant	Filter
(1) Gen											
(2) Bact											
(3) BOD											
(4) COD, NH_3, TO_xN											
(5) H Metals											
(6) Tr Organics											

Source of sample

Water Body	Point	Approach	Medium	Matric
() River	() Maint current	() Bridge	() Water	() Fresh
() Drain	() Right bank	() Boat	() Susp. Matter	() Brackish
() Canal	() Left bank	() Wading	() Biota	() Salt
() Reservoir			() Sediment	() Effluent

Sample type	() Grab	() Time-comp	() Flow comp	() Depth- integ	()Width- integ
Sample device	() Weighted bottle		() Pum	() Depth sampler	

Field determination

Temp: °C	pH	EC	µmho/cm	DO	Mg/L
Odour code	(1) Odour free	(6) Septic	Colour Code	(1) Light brown	(6) Dark green
	(2) Rotten eggs	(7) Aromatic		(2) Brown	(7) Clear
	(3) Burnt sugar	(8) Chlorinous		(3) Dark brown	(8) Other
	(4) Soapy	(9) Alcoholic		(4) Light green	(specify)
	(5) Fishy	(10) Unpleasant		(5) Green	

Remarks

Weather	() Sunny	() Cloudy	() Rainy	() Windy	
Water velocity (m/s)	() High (> 0,5)	() Medium (0,1 – 0,5)	() Low (<0,1)	() Standing	
Water use	() None	() Cultivation	() Bathing and Washing	() Cattle Washing	() vegetable farming in river bed

Figure 35 Sample identification form for surface water samples

4.2.2.4 Checklist for sampling

The following is a list of items, which should be checked before starting on a sampling mission.

- Itinerary for the trip (route, stations to be covered, start and return time)
- Personnel and sample transport arrangement
- Area map
- Sampling site location map
- Icebox
- Weighted bottle sampler
- DO sampler
- Rope
- BOD bottles
- Sample containers
- Special sample containers: bacteriological, heavy metals, etc.
- DO fixing and titration chemicals and glassware
- Thermometer
- Tissue paper
- Other field measurement kit, as required
- Sample identification forms
- Labels for sample containers
- Field notebook
- Pen / pencil / marker
- Soap and towel
- Match box
- Spirit lamp
- Torch
- Drinking water
- Knife

Note that depending on the local conditions, water body, analysis requirements, etc., all items may not be necessary, or other items, not listed, may be required.

Decide on the number of each item that would be required depending on the number of samples to be collected. It is always safer to carry a few numbers in excess.

Ensure that the concerned laboratory is informed of the program and ready to receive samples, particularly those, which would need immediate attention.

4.2.3 Sediment data collection

This theme is described in details, as documentation on sediment acquisition is relatively unusual.

4.2.3.1 Measuring techniques

4.2.3.1.1 General

INTRODUCTION AND DEFINITIONS

The total sediment transported by the stream can be classified under various load and transport modes:

- 1. according to origin:
  - ✓ bed material load, which may be moving as:
  - ✓ bed load
  - ✓ suspended load
  - ✓ wash load moving as suspended load
- 2. according to transport mechanism:
  - ✓ bed load
  - ✓ suspended load, including bed material in suspension and wash load.

The concentrations and related transport rate of suspended load may be measured with quite a large range of devices, making use of either samplers, or other kind of instruments, based on various physical principles. The bed load discharges are usually not determined by direct measurement techniques, but rather indirectly or computed with transport formulas. Sediment transported as suspended load may be measured by:

- the direct method, in which the suspended load transport rate at a point is measured directly with the aid of a single device over a given time lapse;
- the indirect method in which the suspended sediment concentration and the current velocity at a point are measured almost simultaneously over a given time lapse, with the aid of separate devices, and multiplied to obtain the sediment load transport rate.

Sediment transported as bed load can be measured by:

- the direct method, in which the bed load transport rate at a point is measured directly over a given time lapse with the aid of a single device;
- the indirect method in which the movement of the bed material is assessed by an observation, e.g. the movement of dunes resulting from the bed load, over a given time period.

The selection of method and/or device should be made cautiously, taking into account the kind of environment and objectives, e.g. the type of river, the geomorphic setting, the variation of hydraulic conditions and sediment characteristics with changing stages, the data needs and their users. Sediment gauging strategies may be set up by adapting the methods, techniques and instruments depending to the conditions, for one station or for the network in a catchment.

SUSPENDED LOAD

The name “suspended load” is given to all solids that move with the water, away from the riverbed. The suspended load may contain all sorts of solid materials, of all kind of composition and sizes. Usually, the largest part of the suspended load is composed of minerals, such as clay, silt and sand (mostly quarts). The higher the discharge, the more the suspended load will contain coarser particles. These may come from soil erosion in the catchment, from mass wasting (e.g. bank slides), from riverbank erosion, or from riverbed erosion (scouring).

Solid organic material may be present at all or at certain stages only, depending on their origin. They may be freshly detached from the land (such as leaves, branches, trees etc) or enter the steam as vegetation debris. Most of them float at the surface but some may be transported under water, mixing with the sediment minerals and possibly disturbing the sampling.

Before starting sediment measurements in a new station or when introducing new methods and/or instruments, the nature and the composition of the suspended sediment should be observed so that the most suited sediment gauging methods and instruments would be applied, possibly different ones for various ranges in stage. Possible changes in the sediment yield - such as by change of land use or extensive construction activity of roads, railways or hydraulic structures or by operation of hydraulic structures - should be detected in due time so that methods and/or instruments would be adapted accordingly.

The quality of the suspended sediment data does not depend only on a correct operation and maintenance of samplers. Most important is the choice of the appropriate sampler and sampling method and procedure for each of the conditions encountered in the field. In this sense, a flexible gauging strategy should be preferred to a strict application of well-defined measurement procedures. However, this kind of strategy is difficult to implement, as field teams would work with strict instructions, leaving little initiative to observers.

For suspended sediment investigations or measurements, the following characteristics of the sediment should be assessed in view of defining the most appropriate instrument and method:

- the variability with time of the suspended sediment content and how it varies with stage;
- the variability in space - both in the cross-section and in plan form - of the suspended sediment content and how it varies with stage;
- the suspended sediment size, its degree of heterogeneity – in size and composition - and how these vary with stage;
- the bed features (e.g. bed forms, bars, rock outcrops, channel and stream sinuosity) and how they change with stage;

Besides other elements, e.g. those of importance for the geomorphic sets, the following discussion is given to illustrate the relevance of this assessment.

SELECTION AND USE OF SUSPENDED LOAD SAMPLER FOR GIVEN SITE AND STAGE

The selection of the most appropriate instrument or sampler must depend, among other, on the following criteria or conditions prevailing at the observed stage:

- 1. Flow
  - ✓ Water depth
  - ✓ Flow velocity
- 2. Site and measurement conditions
  - ✓ Method of handling/operating the instrument
  - ✓ Elevation of the handling/hanging point above the river bed, or above the water surface, for different stages
- 3. Sediment
  - ✓ Future use of the sediment data
  - ✓ Average suspended sediment concentration at different stages
  - ✓ Distribution of the suspended sediment concentration in the gauging cross-section
  - ✓ Size and/or concentration of the coarsest fraction of the suspended sediment

When required, the change from one sampler to the other would usually take place at the same stage. However, some decisions about sampler/instrument selection can be taken on the site, though some should be taken at higher hierarchy levels. Operators should communicate with the Engineer whenever problems arise in the use of the selected sampler. The Engineer will check the implementation of transparent instructions about the selection of sediment instruments.

RECOMMENDATIONS ABOUT THE SELECTION PROCEDURE FOR SEDIMENTS SETS

In low flow conditions it might well be that the suspended load would be mainly wash-load with little variation in concentration in a single position of the cross-section. However during flood events - the normal and/or the exceptional ones - a significant amount of coarser bed material would be brought into suspension. If the flood is producing large-scale turbulent flow features, such as eddies and boils (the typical up-welling above large-scale bed forms, e.g. dunes), then the instantaneous concentration will change erratically, but in a more or less periodic manner (the sediment "patches" or "clouds" well known in sand-bed streams. These features might change with stage, depending on the adaptation of the bed forms to the changing flow conditions. Furthermore, the presence of an underwater shoal upstream of the gauging section may produce partition of the flow lines around it with confluence flows more downstream. In some cases, this may lead to a sediment "plume", caused by bed material stirred up by the high turbulence at the confluence of the water masses. This picture will obviously change with stage, as the degree of submersion of the shoal varies. In other cases, a rock outcrop may be the source of the increased turbulent energy. In such cases, more bed material can be brought into suspension than would be the case in a smoother reach of the stream.

When the suspended sediment concentration varies significantly, the instantaneous sample taken at 60% of the depth with a streamlined volume-concentration sampler may yield large errors in the computation of the suspended sediment transport rate, e.g. if the sample is taken in the vertical with strongest flow at the moment of highest suspended sediment concentration at the sampling point (overestimation), or when the concentration is lowest (underestimation). Samples taken by depth integration may improve the quality of the data, as the sampler will pass through the patches, making a kind of an average, if the time scale of the periodic variation of the concentration is shorter or of the same magnitude as the sampling transit time. As the patches are carrying coarser material, the error may be significant for estimates of sediment balances. The variability of the suspended load concentration of the coarsest fraction of the load is higher close to the bed. Samples taken at or near the surface may be more reliable, but they may be not so well related to the average concentration over the vertical.

The usefulness of the selection of instruments proposed in "Figure 36 Sampled and un sampled zone of suspended sediment" and "Figure 37 Selection of instruments in sediment balance studies" has to be checked for the Ethiopian situation

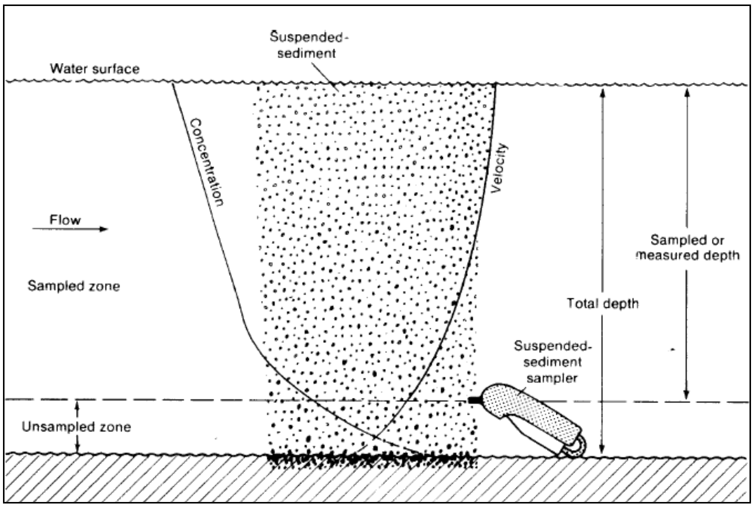


Figure 36 Sampled and un sampled zone of suspended sediment

For sediment balance studies e.g. for reservoir sedimentation, the instruments listed in "Figure 37 Selection of instruments in sediment balance studies » are recommended for the indicated stream categories:

Type of device	Stream size		
	Small	Medium	Large
Suspended load			
bottle	**A,D**	**A,D**	(A)
Volume-concentration, streamlined	**B, C, E, F, G, H, I**	**B, C, E, F, G, H, I**	**B, C, E, F, G, H, I**
Transport rate***	(F), (H), (I)	(C), (E), (F), (H), (I)	(B), C, (E), F, (H), I
Special: pump, turbidity	N.A.	(C), E	F, H, I
Near-bed load			
Pressure-difference	N.A.	(H), (I)	(E), **F, H, I**
Bed load			
Bucket, Box, Pan	**H*, I***	N.A.	N.A.
Pit	(B)*, (H)	N.A.	N.A.
Pressure-difference	(C), **F, I**	C, **F, I**	**C, F, I****
Dune tracking	(E), (H)	(E), H***	(H)

Figure 37 Selection of instruments in sediment balance studies

"Bold" strongly recommended. "Normal"recommended. "Brackets" recommended, but depends on local conditions

* For steep slope rivers / ** for mild slope rivers / *** Complementary to other methods

Refer Figure 26 Classification of measurement sites for selecting the appropriate measurement (page 72) A B C D E F G H & I used here

For problems related to river morphology, the instruments listed in Table 6.2 are recommended for the indicated stream categories:

	Small	Medium	Large
Suspended load			
bottle	**A,D**	**A,D**	(A)
Volume-concentration, streamlined	**B, C, E, F, G, H, I**	**B, C, E, F, G, H, I**	**B, C, E, F, G, H, I**
Transport rate***	C, F, H, I	**C,** E, **F,** H, **I**	**B, C,** D, **E, F,** G, **H, I**
Special: pump, turbidity	N.A.	(C), E	C, F, H, I
Near-bed load			
Pressure-difference	N.A.	**C, F, H, I**	**C, E, F, H, I**
Bed load			
Bucket, Box, Pan	**H*, I***	C*, H*,	N.A.
Pit	(B)*, (H)	N.A.	N.A.
Pressure-difference	**C, F, I**	**C, F, I**	**C, F, I**
Dune tracking	(B), C, (E), F, (H), I	(B), C, (E), F, (H), I	B, C, E, F, H, I

Figure 38 Selection of instruments in morphological studies

"Bold" strongly recommended. "Normal" recommended. "Brackets" recommended, but depends on local conditions

* For steep slope rivers / ** for mild slope rivers / *** Complementary to other methods

Refer Figure 26 Classification of measurement sites for selecting the appropriate measurement (page 72) A B C D E F G H & I used here

4.2.3.1.2 Suspended sediment measurement

INTRODUCTION

Suspended sediment measurement techniques can be classified into direct and indirect methods. The indirect measurement method is the most commonly applied. It considers the sediment concentration as a quality parameter of the water, moving at the same speed as the water. This may be considered as valid for very fine material, at all stages. However, the method is also applied when the sediment sizes vary across the stream channel, over the depth and over the width. Doing so, some errors are generated, which can be avoided by a careful selection of instruments and methods. Information about the variation of particle size and concentration over the cross-section is in principle needed before selecting the instruments and methods. The stream flow measurement method should possibly be adapted to the need of the sediment data, as the degree of detail to be obtained about the flow (distribution in space and time) will depend on the data needs and users. The flow and sediment gauging procedures should be a compromise between simplicity in the field and the appropriateness of the data, taking into account the available resources.

SELECTION OF THE INSTRUMENT

The selection of the kind of instrument or measuring device should be based on the stream type, sediment load and objectives. "Figure 37 Selection of instruments in sediment balance studies" and 'Figure 38 Selection of instruments in morphological studies" are designed to help in this selection.

General rules are difficult to apply, and the recommendations should be interpreted on the basis of the local conditions, human resources, project objectives etc. The type of stream restricts the choice. As a general rule, simple bottle samplers should be selected when suspended load is mainly wash load, streamlined bottle (volume-concentration) samplers when both suspended load and wash load need to be known.

Select always the most simple suspended sediment sampler and procedure appropriate for the site and the stage.

Do not use samplers under flow, site and sediment conditions for which they were not designed. The following working conditions are given as a rule of thumb; however, the conditions prevailing at the site should always be assessed carefully. Sampling may take place:

- by wading
- from a bridge
- from a boat or survey vessel
- from a cableway

These methods are discussed below.

- 1. Sampling by wading can be made when depth (in m) x flow velocity (in m/s) is < 1, with:
  - ✓ Bottle type sampler. To be used only if suspended sediment does not contain significant proportions of medium and coarse fractions.
  - ✓ Light-weight streamlined, fixed-volume point sampler or depth-integrated sampler. To be used when suspended sediment contains more than 5 % medium + coarse fractions and when the sediment concentration of the sample is higher than 100 g/m³.
- 2. Sampling from a bridge when it is less than 5 m above river bed and when the flow velocity does not exceed 1 meter per second, can be made with:
  - ✓ Bottle type sampler fixed to a weight, preferably fish shaped. To be used only if suspended sediment does not contain significant proportions (<5%) of medium and coarse fractions; only a near-surface sample would be taken in higher flows or possibly at 0.6 depth whenever feasible.
  - ✓ Light-weight streamlined, fixed-volume point sampler or depth-integrated sampler. To be used when suspended sediment contains more than 5 % medium + coarse fractions and when the sediment concentration of the sample is higher than 100 g/m³.
- 3. Sampling from a small boat or survey vessel can be made when flow depth and flow velocity do not exceed respectively 5 meters and 2 meters per second, with:
  - ✓ Bottle type sampler fixed to a weight, preferably fish shaped. To be used only if suspended sediment does not contain significant proportions of medium and coarse fractions, only near-surface sample in higher flows and 0.6 depth sample when feasible.
  - ✓ Light-weight streamlined, fixed-volume point sampler or depth-integrated sampler or
  - ✓ Medium-weight streamlined, fixed-volume point or depth-integrated sampler. To be used when suspended sediment contains more than 5 % medium + coarse fractions and when the sediment concentration of the sample is higher than 100 g/m³.
- 4. Sampling from a large boat or survey vessel or from a bridge or cableway when flow depth and flow velocity exceed respectively 5 meters and 2 meters per second, can be made with:
  - ✓ Heavy-weight streamlined, fixed-volume point sampler or depth-integrated sampler. To be used when suspended sediment contains more than 5 % medium + coarse fractions and when the sediment concentration of the sample is higher than 100 g/m³.

GENERAL RECOMMENDATIONS FOR HANDLING PROCEDURES

Depending on the stream depth, hand samplers or cable-suspended samplers can be used and depth-integrated or point samplers have to be applied. Stream velocity in combination with the water depth determines if the stream is wadable or not. A rule of thumb: for depth (m) x velocity (m/sec) >1 the stream is not wadable.

This product affects also the action of each sampler: the larger it is, the heavier and more stable the sampler should be. In difficult situations, it is by trial and error that the type of sampler has to be determined. Samplers to be used in low flow and in shallow water are mounted on a rod, while the others are hanging from a wire or cable. Most samplers are designed so as to have the velocity within the cutting circle of the intake equal to the ambient stream velocity (called iso-kinetic sampling). The well-designed sampler always faces the approaching flow and its intake protrudes upstream from the disturbance created by the sampler.

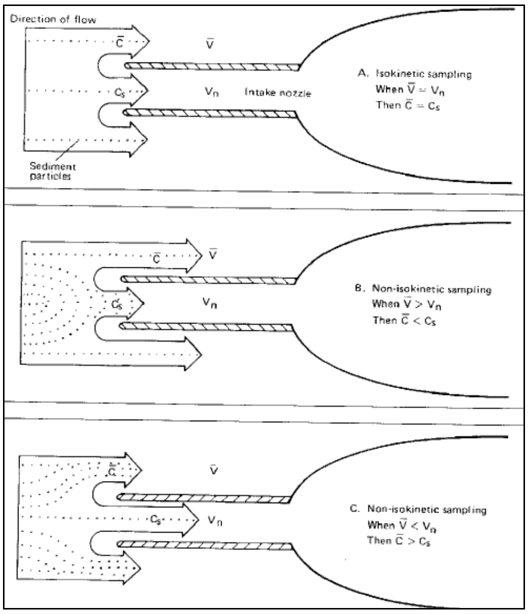


Figure 39 Intake velocity for isokinetic and nonisokinetic sand sampling

This feature is essential when the suspended sediment contains significant proportions of coarse + medium fractions. This explains why the bottle sampler is suited only for low flow conditions and for wash load, i.e. suspended load without medium and coarse particles. The point sampler requires a nozzle/ valve mechanism to control the sampling period and time. Nozzles sizes have also to be defining for sampler. The average velocity, depth of water and time taken for operating the lowering and raising of the sampler are important. Calibration of sampler is needed to determine the nozzle dia matching the site variables above. The overall design of the suspended sediment samplers should always be checked by towing them in still water or keeping them in flowing water of known velocity. This check must be performed with the complete set up used for the measurement, for example with a fish-weight eventually attached for countering the dragging by the flow.

Regular maintenance (check and replacement of the equipment) is necessary to ensure a proper functioning and to have effective and safe working conditions. A file of these operations should be kept at the field office

SMALL HANDLED OR CABLE OPERATED DEVICES

The recommended precautions for operating current meters on a rod apply. A correct assessment of the water depth is essential, prior to sampling. The measurement is usually depth-integrated, but can be at fixed depth (often 60% of the depth) which requires accurate positioning.

For the simple bottle-type (non-iso-kinetic filling), the instrument should be kept vertical and lowered to the desired depth with the mouth closed. The mouth should then be kept open for a time long enough as to have sufficient sample, but without overfilling which would otherwise result in an overestimation of the silt content. The duration of the filling has to be assessed experimentally, as it depends on depth and stream velocity. The sampler can not measure very close to the river bottom, and even when this would be desirable, the operators should be made aware not to hold the instrument in inclined position, what would bring the mouth in a lower position.

For the streamlined-type, the fixed volume sample container can be used in depths up to 2.5 m and in velocities up to 1.5 or 2 m/s, in small and intermediate sized streams. It is very important to have the intake nozzle correctly oriented in the flow.

DEVICES OPERATED FROM A BRIDGE OR CABLEWAY

Some instruments can be used handheld from a low bridge, but usually the device is suspended by means of a winch. Attention should be paid to a correct assessment of the water depth, which may become difficult in strong currents when the height of the bridge above the water surface is large. In this case, dry- and wet-line corrections should be made as for the current measurements.

- For depth-integrated measurements, the accuracy of the positioning is not critical, if the sampler is not lowered too quickly against the streambed, which could otherwise result in catching bed load or bed material.
- For time-integrated measurements, the required accuracy is higher, especially when the gradient of the sediment concentration and of the sediment size over the vertical is steeper, thus closer to the streambed.

DEVICES OPERATED FROM A SURVEY VESSEL

For devices operated from a vessel, dry/air-line corrections are less critical if the flow current is not too strong. In strong currents, the angle at the protractor should be measured. In addition to the recommendations made for the devices operated from a bridge, the risk of wrong depth assessment when the vessel is positioned over a steep riverbed slope should be mentioned, e.g. when at the edge of a submerged shoal. This is important as the vessel may swing around its anchor point due to wind, flow turbulence, especially when in deep water. In that case, the vessel may be stabilised with a second anchor.

SAMPLING FREQUENCY, SEDIMENT QUANTITY, SAMPLE IDENTIFICATION AND INTEGRITY

Sampling frequency

The timing of sample observations is as important as the technique for taking them. Observers should be shown typical hydrographs or recorder charts of their stations or nearby stations to help them understand the importance of timing their samples so that each sample yields maximum information. The desirable time distribution for samples depends on many factors, such as the season of the year, the runoff characteristics of the basin, the adequacy of coverage of previous events, and the accuracy of information desired or dictated by the purpose for which the data are collected.

The accuracy needed in the sediment information also dictates how often a stream should be sampled. The greater the required accuracy and the more complicated the flow system, the more frequently it will be necessary to obtain samples. For a given kind of record, the optimum number of samples should be a balance between the cost of collecting additional samples and the cost of a less precise record. The frequency of collection of bed-material samples depends upon the stability of the streambed at the sample site.

Determining the optimum frequency of sampling is a challenging issue, as sediment load variations do not obey simple laws. Each river and each measurement site may display particular sediment behaviour, depending on factors such as the origin of the sediment, the fluctuations in flow and the possible local disturbances. This can be exemplified as follows:

- **Case A**: Small or medium-size river, reach downstream of a reservoir that is large enough to retain all coarse and medium suspended load even during flood events.
- **Case B**: Large alluvial, sand bed river in which suspended load is composed of a mixture of bed material (sand) and wash load drained from land.
- **Case C**: Medium-size, irregular shaped bed-rock river with sand (medium and coarse sizes) or even pebbles deposited on the river bed in the lean season, carrying during the floods significant amount of sand or pebbles in suspension, but less wash load.

In case A, most the suspended load would be trapped in the reservoir during droughts, making the reservoir outflow carrying little or no suspended load. In this case, it makes no sense to sample continuously during droughts. During flood events, sampling frequency would be low, because of the buffer effect of the reservoir, the transit time of the suspended sediment in the reservoir being large.

In case B, flood events may immediately put into suspension quite some bed material, mainly in the rising phase, while the wash load would arrive at the station later on, depending on the orographic characteristics of the catchment. At the start of droughts, wash load may be deposited on the riverbed, in some preferential zones (e.g. dead water or on shoals/bars). It may then, be resuspended, during small floods, when the flow reworks the riverbed and transports some fine sand and silt. Sampling may be required the whole year round, with low frequency during the stable flows in droughts season (once a week or fortnightly) but higher frequencies in rainy season (daily or even more during floods or quickly varying flow, like the small floods).

In case C, the rocky bed makes a series of pools and rapids in which suspended load would settle at low discharges, making the drought season flow almost sediment free. At the start of the rainy season, the sediment deposited on the bed in the pools will be resuspended, making suspended load containing large proportions of bed material. Even medium flow may resuspend large quantities of bed material due to the high turbulence produced by the irregular bedrock. The bed material will be mixed with the wash load coming from the land drainage. Sediment measurement frequency would be very low during the drought season (monthly or even nil); it would be high during the rainy season, fortnightly or even more.

Obviously, the frequency would also depend on specific requirements, such as the goal or further use of the sediment measurements. Because of this, frequency may be adapted to the changing measurement objectives. Also changes in the river environment or engineering works may affect the relationship between flow and suspended load concentration and size

Sediment quantity

The size range and quantity of sediment needed for the several kinds of sediment analyses in the laboratory are given in "Figure 40 The desired quantity of suspended sediment required for various sediment analyses". Although it is possible to conduct the laboratory operation for particle size analysis in a manner that will also give the sediment concentration, it is best to obtain separate samples for size analysis and concentration analysis.

	Analysis.	Size range (mm)	Desirable minimum quantity of sediment (g)
Size	Sieves		
	Fine	0.062 - 0.500	0.070
	Medium	0.250 - 2.000	0.500
	Coarse	1.000 - 16.000	20.000
	VA tube		
	Smallest	0.062 - 0.500	0.050
	Largest	0.062 - 2.000	5.000
	Pipette	0.002 - 0.062	*0.800
	BW tube	0.002 - 0.062	* 0.500
Exchange capacity	Fine	0.002	1.000
	Medium	0.002 - 0.062	2.000
	Coarse	0.062 - 2.000	10.000
Mineralogical	Fine	0.002	1.000
	Medium	0.002 - 0.062	2.000
	Coarse	0.062 - 2.000	5.000

Figure 40 The desired quantity of suspended sediment required for various sediment analyses

* Double the quantities shown if both native and dispersed media are required

Sample integrity

Every sample taken by a field person should be the best sample possible considering the stream conditions, the available equipment and the time available for sampling. Each bottle sample must be inspected in the field immediately after removing it from the sampler in order to detect significant differences in the amount of sediment and the sediment sizes. A more subtle error in sample concentration may occur when a bottle is overfilled. This error also results in too high a concentration.

Sample identification

Explanatory notes such as time, method or location, stationing, unusual sampling conditions etc. can be recorded on the sample or inspection sheets.

4.2.3.1.3 Bed load measurements

Bed load gauging (also called bed load transport measurement) is often mixed up with bed material sampling. Bed load gauging is the measurement of the amount of sediment that is moving as "bed load", i.e. rolling, sliding and bouncing (in "siltation") on or over the stream bottom, while bed material sampling is the collection of the material composing the stream bottom. Bed load transport measurements are rightly considered as very difficult and complicated. The reasons for this are:

- the poor understanding of the transport processes: (what are we measuring?)
- the very irregular character of the particle movement in the bed load
- the disturbance of the flow and of the bed load transport processes when a sampling device is lowered on the stream bottom.

As bed load accounts only for a small fraction of the total load and because they are difficult to perform, bed load transport measurements are most often discarded and replaced by computations. However, the uncertainties on computations with bed load transport formulas are as bad as those on measurements. Moreover, the economic importance of bed load observations is usually underestimated, especially in sand bed streams.

Because of the complexity of bed load transport measurements, extensive training is required. Besides the obvious need for training in a proper operation and maintenance of bed load instruments, bed load gauging strategies are required to get the most representative samples and measurements.

Bed load measurements should be avoided if a good training and a thorough follow up of the measurement procedures can not be ensured.

BED MATERIAL SAMPLING

Introduction

Data on the size of material making up the streambed (across the entire channel, including floodplains) are essential for the study of the long-range changes in channel conditions and for computations of unmeasured or total load. The composition of a streambed is the result of erosion and/or deposition processes, i.e. the balance of the actual sediment load of the river and the transport capacity of the flow. Some river reaches (the "degrading" ones) are progressively incising in the underlying geological formations. These may be rock or soil, and the rate of scouring will depend on the physical and mechanical characteristics of the bed material. Other river reaches (the "aggrading" ones) are progressively building up the streambed with the sediments carried by the flow. In one location of a "poised" river reach, scour and deposition alternate, depending on the at-the-time prevailing conditions of flow and sediment load.

A common feature of streambed is the frequent presence of bed rock. In this situation, the streambed may display a variety of bed materials, going from hard, erosion resistant bedrock to large boulders, pebbles, gravel, sand, silt and clay, sometimes all of these in the same river reach.

The nature and physical properties of the streambed has to be well identified when dealing with projects, studies and works, as related to dams and gates, off-take or water-withdrawal structures, bridges, bank protection works, etc. For each of those, different kind of information may be needed. Collection of relevant or useful data on the bed material is quite complex matter, and routine procedures are not easy to define, certainly not when dealing with a heterogeneous streambed.

There is quite often some confusion in the terminology, between "bed load" and "bed material". The bed material is what is found in appreciable quantity in that part of the streambed affected by the flow and eventually transported by it. The bed load is composed of those sediment particles moved by the flow in contact with or very close to the streambed. In some river reaches, the bed load composition is quite the same as the bed material; this is the case in dynamic sand bed rivers that are continuously reworking their bed. In other river reaches, the load transported on the bed (the bed load) may have a composition quite different from the underlying bed material. This is among other the case for rivers: (a) flowing in a hard bedrock streambed, or over a bottom composed of loose soils deposited in earlier geological times, or (b) when the river flow processes have produced a special bed material by sorting the sediment particles (the best known example is the "armoured" layer formed eventually in gravel bed rivers).

When the bed material and the bed load are strongly graded, the composition of this bed material may vary widely in the same river reach. Larger particles may be found on the bottom of the stream during flood events, while the bed material visible during droughts may be fine graded. Particularly in steep or medium slope rivers carrying very different particle grades, the scour, transport and deposition pattern may produce a strong heterogeneity of the bed sediment.

Usually, bed material is sampled three times a year at the gauging cross-section: once during the flood period,, once before and once after this period. Bed material is sampled from the flowing part of the river, as well as from the dry part when required at low stages. A minimum of three samples are taken at a date of flow gauging, most often only three.

Bed material is usually sampled with simple means. In the flow, sediment is collected by means of a scoop-type sampler. In the dry bed, the top layer of 10 to 15cm is removed after clearing it from vegetation. A 30 to 40cm pit is then dug out and samples taken from the pit walls, trying to have them as representative as possible. The samples are reduced to the required quantity by the cone and quartering technique. These reduced samples are collected in polyethylene bags, placed themselves in thick and resistant cloth bags, labelled and sent to the laboratory for analysis.

The sampling procedure is standard for all kind of streams and does not make special recommendations for particular situations, such as hard bed-rock rivers where loose sediment alternates with rock. The selection of sampler and sampling procedure should depend on the heterogeneity and variability of the bed material in space and time, as well as on the required information, thus depend on the objectives.

Bed sampling technique

The selection of the sampler will primarily depend on the requested bed material data:

- Surface sediment
- Surface and sub-surface sediment

For sediment transport studies in streams with homogeneous bed load and bed material (e.g. in dynamic sand bed rivers), sediment samples taken with a surface sampler will yield the relevant information.

For bed scour studies in flowing streams, such as for the design of bridge piles, sub-surface samplers may be needed in case the bed material composition is heterogeneous and varying in space and time.

For sediment silt and mud deposition studies, as in reservoirs, behind dams, or in estuaries, the sampling must be conducted sub-surface, eventually in thick layers of deposits, in combination with soil density measurements made with in-situ probes (no samples taken).

Most important is to assess the need for undisturbed sampling, allowing possibly sampling of disturbed samples. Sampling of hard bedrock requires drilling technology and is not considered here.

The ***choice of the sampler type*** should be governed by the nature of the bed material and the flow conditions when sampling:

- Cohesive soils, consolidated
  - ✓ Sub-surface samples can only be taken with corers, preferably piston corers
  - ✓ Surface samples may be best taken with scoop-type devices.
- Cohesive soils, loosely consolidated
  - ✓ All samples would be disturbed
  - ✓ Surface samples may be taken with a pumping system, for all mud densities up to 1.15 or possibly 1.2
  - ✓ Sub-surface samples are very difficult to take, only with corers, but which design usually does not allow to take undisturbed samples.
- Non-cohesive soils, fine graded (silt and/or sand)
  - ✓ Sub-surface samples can only be taken with corers, preferably piston corers
  - ✓ Surface samples may be taken with scoop-type, grab-type, and dredge-type devices.
- Non-cohesive soils, medium or coarse graded (sand, gravel)
  - ✓ Sub-surface samples are difficult to take and will always be disturbed ones; if armour layer covers the streambed, it must be first removed (only possible on dry bed); sub-surface sampling may also be taken from man-made pit
  - ✓ Surface samples may preferably be taken with scoop-type bucket sampler, because in the other samplers the fines would easily be washed out when raising the sampler to the water surface.
- Non-cohesive soils, coarse to very coarse graded (gravel to boulders)
  - ✓ Sub-surface sampling should be made from dry bed in a pit, whenever possible
  - ✓ Surface samples are difficult to take as only a very large sample size would yield statistically representative results; as this kind of bed material is usually found in streams with high slopes, having dry bed most of the time, visual methods such as with camera pictures or counting are best suited.
- Other selection criteria's, advantages/disadvantages
  - ✓ Core samplers: usually heavy equipment, difficult to operate under water at a flow and sediment gauging site when flow velocity is high; best suited for fine graded material (clay, silt and sand); piston-type corer gives the least disturbed sample
  - ✓ Dredge or drag-bucket-type samplers: Easy to use from a boat; liable to be affected by washing out of material during the actual sampling; sampler may be dragged when (1) sailing slowly up the river or (2) letting drift the boat from up- to downstream the sampling station (second procedure appropriate when flow becomes too strong)
  - ✓ Scoop-type grab samplers, 90° closure, not streamlined: The sampler is difficult to operate in strong currents and is liable to be affected by washing out of material, mainly fine particles.
  - ✓ Scoop-type grab samplers, 180 degrees, streamlined: The streamlined sampler can easily be lowered to the streambed even in velocities as high as 2 to 3 metres per second.
  - ✓ Scoop-type grab samplers, 180 degrees, not streamlined: The sampler can not be properly lowered to the streambed in high velocities.

Comment on importance of bed forms

Bed forms, mainly the large ones, affect the near-bed flow pattern and may produce sediment sorting when the stream's sediment load is graded. Bars and dunes may display different bed material sizes over their area. A typical example is the bar in the foothill reaches where the river slope changes from steep to mild and where the sediment load is heterogeneous in size. As these bars may be quite large, with characteristic sizes – bar width and wave – similar to the width of the river, one or even three samples may not be statistically representative for the streambed.

The heterogeneity should be assessed at the Central Office and the optimum number of bed samples determined on the basis of a special survey; also the location of the samples needed for getting a representative average should be clearly stipulated relatively to the bed form, e.g. on the top, in the trough between two consecutive bars, on the lee side, on the upstream side.

Materials Coarser than Medium Gravel

Gravel in the 2 to 16 mm range can be analysed by mechanical dry sieving. In order to obtain a representative particle size distribution, the size of the sample to be collected must be increased with particle size. The size determination of very large particles can be done by the pebble-count method, which entails measurement of the dimensions of randomly selected particles in the field, or by using special particle-size analysers. A reference photograph should then be made of the streambed during low flow. The sizes registered on the counter of the particle-size analyser must be multiplied by the reduction factor of the photograph.

BED SAMPLING METHODS

Bed-material samples are often collected in conjunction with a discharge measurement and/or a set of suspended- sediment samples. By taking these samples at the same stationing points, any change in bed material on radical change in discharge across the stream that would affect the sediment discharge computations can be accounted for by subdividing the stream cross-section at one or between two of the common verticals.

SPECIFIC PROCEDURES

As samples are obtained across the stream, the field person should visually check and compare each sample with the previous samples to see if the material varies considerably in size from one location to the next. Proper labelling of bed-material samples is not only necessary for future identification, but also provides important information useful in the laboratory analysis and the preparation of records.

4.2.4 Resource needs for Quality data collection / Laboratory

The water quality monitoring net work consists of 188 sampling stations from which samples will be collected regularly at a frequency of once in every quarter of a year. Each sample collected will be analysed for over thirty different parameters ranging from common anions, to heavy metals and pesticides as described in the preceding chapters. Presently, the hydrology department of the MoWR do not have a full fledge laboratory in place that can fully undertake the analysis of samples to be collected from the water quality monitoring network stations. The sediment and water quality laboratory being run by the hydrology department is not well equipped with necessary laboratory instruments. Its present capacity to undertake the analysis of water samples is very small and has limited capacity. The former MoWR laboratory which is situated inside the head office building in Addis Ababa has long been transferred to the water works design and supervision enterprise. The challenge at this stage is then how to start the monitoring programme, which laboratories to use at the initial stages, and how the monitoring programme should develop its own laboratory facilities in the process. Clearly, if the water quality monitoring programme is going to be sustainably run for a long time, it would have to rely on capable, dependable and fully committed laboratories. Thus the first recommendable option in this respect would be to strengthen the sediment and water quality laboratory of the MoWR found under the hydrology department by providing it with additional analytical instruments, chemicals and skilled man power. The capacity strengthening should enable it to undertake analysis of a broader range of the water quality parameters than it does now. However, until the sediment and water quality laboratory of the MoWR build its capacity and become self sufficient, it will be possible for the monitoring programme to pilot-start by using the spare capacity of other laboratories present in Addis Ababa and the regional capitals. Recognised alternative laboratories in Addis Ababa include the Addis Ababa EPA laboratory, Addis Ababa Water and Sewerage Authority, Ethiopian Geological survey laboratory, the Addis Ababa University laboratories and the water works design and supervision enterprise laboratory. These laboratories have the capacity to undertake physico-chemical analysis of water samples.

The AAEPA, AAWSA, WWDSE and EGS laboratories do provide their service to outside customers by charging fees. The AAEPA lab is an emerging advanced laboratory that can undertake a broad range of analysis on the water quality samples.

On the other hand, the water quality stations selected for constituting the monitoring network are fairly distributed throughout the river basins and hence collecting samples from them will obviously require travelling to all parts of the country. If all samples have to be brought to a laboratory in Addis Ababa, it would entail travelling thousands of kilometres back and forth of the capital to accomplish one round of sample collection. In addition it will require mobilizing about 8 teams to collect samples from the river basins at once. This will create a considerable burden not only on resources but can also hamper the timely delivery of samples to the laboratories. Thus it becomes necessary to explore alternative options in the regions which can lessen the burden. The survey conducted as part of this study has identified the following alternative options to access laboratories for analysing water samples in the regions.

1. Strengthening and using the regional branch offices of the hydrology department
2. Contracting regional water bureaus and Universities found in selected regional capitals
3. Establishing and using river basin authorities and respective laboratories

Since it is the hydrology department which will be responsible for running the water quality monitoring programme, stepping up the role of its branch offices found in the regions will create an opportunity to samltanuosley run water quality and quantity monitoring programmes. It is known that there are already some efforts in some of these branches to conduct in-situ measurement of certain water quality parameters using field kits. Therefore strengthening the capacity of the branch offices to be able to conduct in-situ measurements of a wider range of parameters than pH and electrical conductivity by providing them with field kits capable to measure a variety of parameters will be a preferable option to start with. While the branch offices conduct the in-situ measurements on the monitoring stations, they will also collect samples, preserve them and get them ready to be forwarded to the selected laboratories for analysis of the remaining parameters. Running the sample collection and in-situ measurements by strengthening the branch offices will shorten the distance one needs to travel in order to collect the samples from each station.

The other option which can complement to the suggestions made above is the use of laboratories found in the regional capitals. As mentioned earlier, there are laboratories in the regional water bureaus and Universities. The Universities of Bahirdar, Mekelle, Arbaminch, Alemaya and others are some among others which have laboratories capable for conducting water quality analysis. The hydrology department can approach these different institutions to work together on running the water quality monitoring programme based on mutually agreed modalities. The idea of working in collaboration with such institutions also applies to the aforementioned laboratories found in Addis Ababa. Before launching the water quality monitoring programme at national scale, the hydrology department should develop a new project proposal and secure the necessary funds to run the monitoring programme at pilot level. The project to be developed should seek and forge the modalities of running the pilot-water quality monitoring programme in collaboration with selected laboratories in Addis Ababa and the Regions. It should be mentioned here again that the project to run the pilot water quality monitoring programme is also very essential to finalize the selection of micro-sites for each of the sampling stations in the network.

In the long term, however, the river basin approach to water quality monitoring should come into play. It will be more appropriate for River basin authorities to establish their own laboratories which will help them to run the water quality monitoring programme in a more detailed way and to generate data on other areas of their interest.

4.3 SUPERVISORY CONTROL AND DATA ACQUISITION SYSTEM-EQUIPMENTS

Description of the network (water level) will follow the rules defined by the CIM methodology, already defined here before.

4.3.1 Definition of SCADA system

Supervisory Control and Data Acquisition System (SCADA) represents a system which consists of a number of Data Collection Platform (DCP) collecting field data connected back to a master station via a communication system". These field data are transmitted to a master station via the landlines or wireless media (radio, satellite, microwave, etc.). The information obtained by a master station can be used for monitoring only purposes, for supervisory remote control. Along with these tasks, parameter estimation together with data reconciliation and real-time optimization are very important features of any SCADA system. The objective of any measuring device/transducer/transmitter is to deliver information about the process parameter to operator with highest possible accuracy and in a timely manner. This is dictated by operational conditions of the process of interest, and by occupational, health and safety issues which should be taken into account when designing a process itself and SCADA system for it. Very often, SCADA systems operate with real-time data in order to carry out real-time optimization of various processes, which translates to "more efficient, reliable and safer operations"[1]. Since the profit is the driving force for all new developments, then application of SCADA systems, in the long run, will reduce operational costs of the process monitoring and control.

SCADA system has several levels of hierarchy:

- field level instrumentation- level 0 of the CIM: Sensors;
- remote terminal units- level 1 of the CIM: Data Collection Platform (DCP);
- communication systems- level 2 of the CIM: Data Transmission system;
- supervisory stations- level 3 of the CIM;
- Management data processing- level 4 of the CIM.

Field instrumentation represents smart sensors, transducers, transmitters which are located locally on various process units. They collect and transmit all necessary field information to a central location. Sometimes, when there is no need to collect real-time data, data loggers are used. The combination of the above mentioned hardware for collecting process data represents DCP. In order to deliver the collected filed information to a central location, there is a need for a communication system. Such systems provide the pathways for communications between the master station and the remote sites". Landline (telephone), radio, microwave, and satellite systems are among widely used for remote data transmission. Once this information from various DCPs been delivered to a master station, its software start to collect these data, record them, analyze these data, compare them with set-points, provide operator interface, and perform control actions for required controlled process parameters. The last element of SCADA system is a control centre, the data processing computer system which carries out real-time calculations and outputs the recommendations to various levels of river management in our case.

4.3.2 Sensors – CIM level 0

4.3.2.1 Glossary

Pressure sensors, transducers and transmitters For the purposes of this manual the term pressure sensor has tended to be used to describe a DWLR of the pressure sensor type. This is a general collective term, which is used to describe two types of sensors:

- 1 Pressure transducers;
- 2 Pressure transmitters.

There is a fundamental difference between the two, even though the term pressure transducer is often used to cover both types. The difference between the two types is as follows:

In a typical pressure sensor design an electrical potential is applied to one part of the circuit and an equivalent electrical potential sensed as an output from another part of the circuitry, the output being related to the degree of applied pressure at the transducer diaphragm.

Conditioning/signal processing circuitry is necessary to accurately sense and discriminate the resulting output and convert it into a form for storage on a logger in digital format e.g. 4 - 20 mA or 1 - 5 V

For a pressure transducer the conditioning is undertaken remote from the sensor i.e. at the logger, whereas for the pressure transmitter this conditioning takes place at the sensor and the processed signal is transmitted back to the logger.

Flash Powering Technique to power a sensor for only a few microseconds for a meaningful and repeatable measurement, while only draining the battery for a very small fraction to enlarge the life time of the latter.

Linearity A sensor would be perfectly linear in its response to changing water level if a small change in water level, anywhere on the measuring range of the sensor, would result in the same change of the presented instrument reading. Linearity is defined in terms of two descriptors:

FRO which stands for Full Range Output (sometimes FSO - Full Scale Output), and is used to indicate that any given value of pressure sensed by the device in question may be expected to be accurate to within a stated percentage of the FRO value e.g. +/-0.1%FRO (a typical value for a modern-day device).

BSL which stands for Best Straight Line - a line midway between the two parallel straight lines closest together and enclosing all output vs. actual pressure (water level) values on a calibration curve.

Given indication of the two defining values referred to above, it may be known that a sensor will represent true pressure state, at any point within its intended operating range, and in terms of its inherent linearity characteristic, within + or - x% of the full scale value itself. An important, and sometimes operationally relevant, inference of this is that, in terms of absolute accuracy i.e. how accurate a sensed value may be, at any part of the transducer's operational range as a percentage of itself, low range values will be less accurately represented than high.

Hysteresis The maximum difference in output, at any value within the specified range, when the value is approached first with increasing and then with decreasing value. This reflects the degree to which any two separate determinations of the same true value may differ if the previous states of true input have been respectively less than and greater than the present true input state. A low hysteresis value is clearly desirable, and is normally expressed as x% FRO (BSL) and often as a combined statistic with linearity.

Temperature Effects Even though the effect may be small, may be well understood, and may be capable of electronic (or, even, software) compensation, to a lesser or greater extent all pressure sensors are sensitive to changing ambient temperatures. Typical expressions of this phenomenon include:

Temperature Error Band, i.e. the error band applicable over stated environmental temperature limits normally expressed as "% FRO", and representing the additional error (i.e. on top of non linearity, etc.) associated with changes of ambient temperature (at the sensor) outside the limits specified.

Thermal Zero/Span Shift, the Zero Shift due to changes of the ambient temperature from Room Temperature to the specified limits of the Operating Temperature Range - analogous to the Temperature Error Band, but applying solely to the accuracy with which true zero (or Full Scale) input is represented as output.

Compensated Temperature Range, the range of ambient temperatures within which there is in-built compensation to nullify the potential effects of changing temperature upon device output usually expressed as an upper and a lower temperature value e.g. -2oC to +30oC.

Zero Offset. The within which the vented gauge pressure type DWLR reading may be expected to lie when in air. In other words, the reading may not deviate from zero by more than a specified margin, e.g. 0.02 m. he zero offset usually is compensated for during the instrument set-up procedure. The remaining error source then is the zero stability.

Zero Stability. Zero stability is expressed as the maximum change of zero offset that is permitted over a period of time, usually 1 year. In order to maintain rated accuracy, the zero change should be regularly checked.

Ageing Effects (or **Long Term Drift**). Over a sufficiently long period of time, any of the performance characteristics of a pressure sensor device may alter, due to the simple ageing process altering the physical state of its component parts - quite aside from the effects of general operational stress or of chemical processes (oxidation as a result of moisture ingress, for example, or corrosion through the ingress of gaseous chemicals). A pressure sensor is, inevitably, an assemblage of numerous separate components, made of almost as many different materials, each with its own characteristic reactions to thermal cycling. At every material interface, a greater or smaller degree of stress will be engendered whenever the materials' temperatures change and, accumulating, over many such cycles, physical changes take place that can affect the overall device calibration. The existence of the ageing process should be recognized through periodic calibration checks of all operational parameters detailed in the basic device specification - at intervals of time no longer than (say) three years, with less wide-ranging tests applied (in the field if necessary) at no greater than annual intervals.

In any organization that uses pressure sensors as an everyday hydrometric tool on which reliance is to be placed, a high quality, portable Pressure Tester will be likely to be an essential support device. This device, in turn, should be subject to rigorous quality assurance procedures that allow its performance to be traced back confidently to an accepted Standard.

Vulnerability to Atmospheric Electro-Magnetic Effects. Pressure sensors are not only delicate in their mechanical construction (at least at the pressure sensing diaphragm), they can be sensitive also electrically. They are essentially (in the main) low-voltage, low-current devices. Also, the essence of their installation places, more often than not, their sensing element at some significant distance from other associated electronics, joined by (perhaps) many meters of power and signal cable - potentially a very effective antenna.

Ambient Electric "Noise" is present everywhere and, without appropriate precautions, can easily be picked up by instrumentation cabling to a degree that swamps the signal characteristic of interest. To protect against this, transducer cabling is invariably of the screened variety, and normally works effectively to exclude unwanted electrical noise. However, care is needed at installation time to ensure that the total integrity of cable screening is preserved. Joining lengths of cable is best avoided and, if unavoidable, requires the utmost care.

In joining transducer cable lengths, great care is also required to preserve the integrity of the ventilation tube. Similarly, in routing cabling between transducer and instrumentation, care is required to ensure that the ventilation tube is not blocked by being kinked.

Lightning can also be a source of danger to transducers and their associated instrumentation (indeed it is a hazard to most electronic devices deployed outdoors, or in the near-outdoors). In the case of submerged pressure transducers, a very effective path to earth may be provided for the high static voltages generated by atmospheric electricity as lightning. Where possible, electronic protection against high transient voltages should be incorporated, in the installation design of all such devices (taking manufacturers' advice as appropriate). Almost inevitably, however, there will be instrumentation losses from time to time to lightning activity -relative incidence being, often, quite location-specific, with some sites much more vulnerable than others. Spares-holding policies should take this into account.

Overall Device Sensitivity. Sensitivity is the smallest change in the measured value that will result in a measurable change in transducer output. This parameter is a joint function of the mechanical sensitivity of the pressure diaphragm itself, and of the supporting electronic circuitry. It is not always indicated in a product specification, but may reasonably be assumed to be no worse than the smallest value of any of the stated parameters that define product performance in general. It is unlikely to be better than such a specified value.

A given degree of sensitivity required in the sensing of the water level is likely to be best achieved through careful selection of transducer range. If there is a conflict in the overall operational specification between range and sensitivity (or Record Resolution), it may be possible to reconcile the difficulty through use of two or more transducers, deployed to cover different parts of the Required Range overall.

If recourse is had to such a multi-transducer operational strategy, care will also need to be taken to consider the Over-Ranging Capability of one or more of the deployed transducers i.e. its ability to withstand, without damage to its performance, pressures significantly in excess of its nominal range. Note that a "Four-Times-Range" over-pressure provision is likely to be readily achievable by many commonly available proprietary transducers.

Note also that, in some applications, undue sensitivity in the transducer to changing input may be an operational disadvantage (e.g. response to wave action). Therefore, the sensor needs to be selected accordingly.

Electronic/Software Wave Filter. Conventional float and counterweight water level recorders require stilling wells in order to dampen out oscillations caused by wave action. Pressure transducers when used in rivers and reservoirs are also subject to wave action and some form of filtering or damping is required. This can be undertaken either electronically or in the logger software.

4.3.2.2 Stage measurement techniques- Surface Water

The stage or gauge height is defined as the elevation of the free water surface of a stream relative to a local or national datum, measured by a gauge. Stage or gauge height is usually expressed in meters and hundredths (cm) or thousandths (mm) of a meter depending on the resolution required.

Records of stage may be of direct or indirect interest:

- direct interest: e.g. for flood or low flow levels, reservoir levels, etc., and
- indirect interest : to derive a second variable, e.g. the discharge of a river using a stage-discharge relation (Q = f1(h)) or the surface area and/or volume of a reservoir as determined by a stage area and/or stage-storage relationship (A = f2(h), V = f3(h)).

The determination of stage is therefore an important measurement in hydrometry. The reliability of continuous records of discharge derived from a stage record depends to a large extent on the quality of the stage record. Instruments and installations used to measure stage range vary from the very simple to highly sophisticated.

4.3.2.2.1 Overview of water level gauges

Water-level gauges in use comprise:

- Non-recording gauges, including :
  - ✓ Vertical staff gauges
  - ✓ Inclined or ramp gauges
  - ✓ Crest (maximum water level) stage gauges and
- Recording gauges, covering
  - ✓ Float system with autographic recording (Sub-section 6.1.6),
  - ✓ Float system with digital recording (Sub-section 6.1.7), and
  - ✓ Immerged pressure sensor (piezo - resistive or bubbler pressure)
  - ✓ Aerial sensor (radar or ultrasonic)

4.3.2.2.2 Vertical staff gauges

A staff gauge normally consists of a measuring plate fixed to a post set in concrete. The measuring plate is of enameled steel or stable FRP with graduations of 0.01 m, see “Figure 41 Staff gauge”. The staff gauge is bolted to a concrete or steel pole. The pole has slots to adjust the level of the plate. The staff gauge may be painted on a well established and stable structure, like a bridge pier or retaining wall. At all hydrometric stations a staff gauge is required to measure the water level. The staff gauge is used:

- either as the sole means of obtaining the level
- or as a reference gauge to set and check the water level recorder

Where short interval data is required, e.g. small, responsive catchments the use of manually read staff gauges will be inadequate unless several observers are rotated (shift system) so that an observer is on site at all the time.

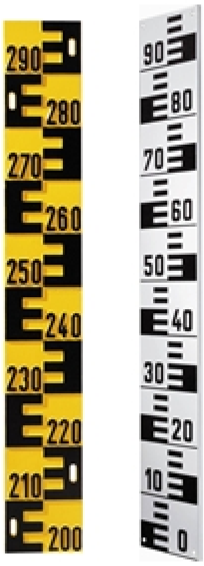


Figure 41 Staff gauge

The following aspects of staff gauges are subsequently dealt with:

- Site requirements
- Station layout
- Installation aspects
- Operational aspects
- Maintenance
- Accuracy
- Staff requirements
- Auxiliary gauges
- Gauges attached to a stilling well
- Advantages and disadvantages

SITE REQUIREMENTS

The staff gauge should be located on stable banks, or attached to bridge piers or reservoir walls. At all times one should be able to read the water level from the gauge. Flow conditions should be such that little turbulence and wave action is experienced near the gauge posts to reduce measuring errors.

STATION LAYOUT

A single set of gauges is normally employed at a gauging station. If apart from the stage also the fall is to be measured auxiliary gauges are required. When a stilling well is available to accommodate a recording gauge, staff gauges are placed inside and outside the stilling well.

To level the gauge, two permanent benchmarks of known level relative to mean sea level (MSL) should be close to the site. If these are not available two independent sites within 500 m of the river should be available where station benchmarks can be installed relative to an arbitrary datum. This arbitrary datum should be related to "MSL" as soon as it is practically possible. These sites should be whenever possible free from possible natural or human interference.

INSTALLATION ASPECTS

Vertical gauges are usually installed in sections of 2.0 meters length with a series of gauges stepped up the bank to a level exceeding the maximum flood level, see "Figure 42 Vertical staff gauges stepped in series up a riverbank". For stations where the water level is controlled by a weir, the zero of the gauges should coincide with the lowest weir level. For stations with a natural control, the zero must be lower than the lowest water level in perennial rivers and preferably at, or lower, than the lowest bed level in non-perennial rivers. The zero of all gauges should refer to mean sea level datum (MSL). The numerals must be distinct and placed so that the lower edge of the number is close to the graduation to which it refers. There must also be provision for the meter numeral on each meter length of plate.

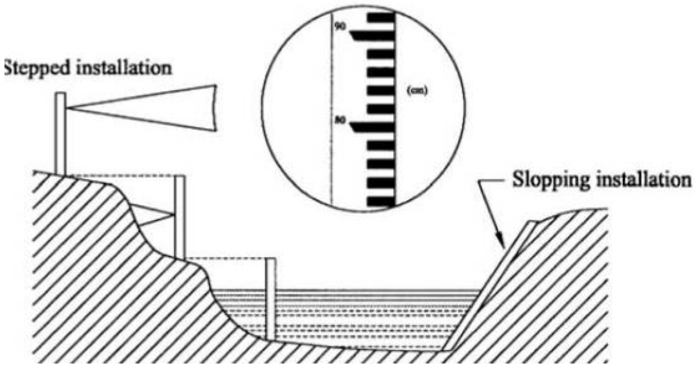


Figure 42 Vertical staff gauges stepped in series up a riverbank

Vertical staff gauges are fixed to reinforced concrete or angle iron supports, with cement concrete foundations extending to a level reasonably free from erosion or disturbance (usually about 0.75m). Angle iron supports are generally least vulnerable to damage by flood debris but in certain areas may be subject to theft.

OPERATIONAL ASPECTS

The staff gauges are manually read at fixed times each day. The reading times may vary seasonally. Where appropriate the gauges are also read during flow measurements

The accurate recording of time is important, particularly during periods of rapidly varying stage. It is essential that all observers possess or have access to a reliable watch or clock.

Consideration must be given to the visibility of the gauges under all flow conditions, for example where access to the bank becomes difficult in flood conditions and the gauge becomes more distant. The simplest solution may be to provide the observer with a simple pair of binoculars. The averaging of stage readings during choppy but steady water conditions could improve the accuracy. However, this requires that a good, reliable observer is available.

MAINTENANCE

Stability of staff gauges cannot be ensured and they are often exposed to movement or flood damage. Gauges must therefore be check surveyed with a minimum frequency of twice per year in the pre- and post-monsoon and on the occurrence of any observed disturbance or damage. The zero of the gauge plates and each individual gauge plate must be connected to a temporary or permanent benchmark and the circuit closed to the starting point with an error not greater than 5 mm. When a gauge is found disturbed, it should be reset immediately and survey information be recorded in the Field Record Book

ACCURACY

When the water level is gauged to estimate the discharge, the level should be accurate relative to a local datum. In such cases accuracy relative to national datum is not of importance. When flood levels are of concern then the accuracy relative local or national datum may be of concern.

The uncertainty in the water level reading is composed of:

- uncertainty in the zero of the gauge, and
- uncertainty in the gauge reading

The uncertainty in the zero of the gauge depends on the accuracy of the levelling to the benchmark. The uncertainty in the gauge reading is a function of the accuracy of the graduations on the gauge plate, the hydraulic condition and the quality of the observer

Under calm conditions, the staff gauge can be read to an accuracy of ± 3 mm. However, the reliability of observations is to a far greater extent dependent on the ability and reliability of the observer. This is an important consideration in the selection of station equipment and operation.

STAFF REQUIREMENTS

When staff gauges are used for reference gauging one reading per day will do, so one observer will be sufficient. Stations, which operate with staff gauges only, are heavily demanding of manpower as three observers are required to ensure readings over the full 24 hours. This is a general requirement during flood periods when levels change rapidly.

AUXILIARY GAUGES

At river sites two more sets of auxiliary gauges, set to the same datum, may be installed to determine the fall or water surface slope. The fall is of interest for the computation of discharge to be able

- to correct for backwater effects,
- to estimate the hydraulic roughness for rating curve extrapolation, or
- to convert stage to discharge using the slope area method;

For the installation of auxiliary gauges there are two conflicting requirements:

- the distance between gauges should be sufficient to detect differences in water surface slope between the cross-sections,
- the time of measurement at the gauges be precisely synchronized if the stage is changing rapidly

Generally, if one assumes that the uncertainty in level measurement at the upstream and downstream measurement gauges are the same, then the distance between the gauges should be sufficient for the fall to be not less than twenty times the uncertainty in the measurement at one gauge. Hence, if the uncertainty in the measurement at one gauge is 0.01 m then the gauges should be distanced such that the fall is at least 20 x 0.01 = 0.20 m. Then, the uncertainty in the fall becomes: $\sqrt{2} \times 0.01 = 0.014$ m.

Greater is the distance between the gauges, greater is the difficulty in ensuring time synchronization. These difficulties must be considered when setting up and operating such stations; it may have consequences for the number of staff required.

GAUGES ATTACHED TO A STILLING WELL

When a stilling well is used to accommodate an electronic recording gauge, staff gauges are installed inside and outside the well, both having the same zero datum. The standard reference gauge must remain the outside gauge as the level on the inside gauge may be affected by blockage of the stilling well inlet pipe so that both staff gauge and recorder are registering the same inaccurate reading. In this case, comparison of inside and outside gauges provides a check on the functioning of the stilling well.

ADVANTAGES AND DISADVANTAGES

Staff gauges are always required at hydrometric stations. To their advantage counts: staff gauges are simple, robust and easily understood. Disadvantages are that they do not produce a continuous record and that they are manually read.

4.3.2.2.3 Inclined staff or ramp gauges

Inclined staff or ramp gauges are staff gauges designed to follow the natural slope of the riverbank, see Figure 6.3. Though in the field generally vertical gauges are applied, occasionally inclined gauges are applied provided that the riverbank is stable. Aspects dealt with for the vertical gauges are in general also applicable to inclined gauges

Figure 43 Inclined staff gauges

ADVANTAGES

Inclined gauges are generally less prone to damage than vertical gauges, where rocky and stable banks exist. They also allow more accurate readings of the water level because of their better resolution.

DISADVANTAGES

Inclined gauges have to be individually prepared owing to the natural variation in slope angle. They should therefore only be used where flood damage to vertical gauges is expected. Also, they have found to be prone to movement and damage caused by bank collapse and slippage. As they are more complicated and time consuming to install and more costly to replace than vertical staff gauges, they are not currently in common usage in Ethiopia.

4.3.2.2.4 Crest Stage Gauges

Crest stage gauges, sometimes referred to as maximum water level gauges, are devices for obtaining the elevation of the peak flood level of a stream where continuous observation is not available. These are comparatively simple and inexpensive devices. The four most common methods are:

- 1 Color change gauges: a water sensitive tape, which changes color when in contact with water, is enclosed in a vertical tube. Water enters the tube at the base and washes off the color up to the maximum height reached by the water, see Figure 44 Maximum Flood Level (MFL) Gauge.
- 2 Greasy pole: the gauge typically consists of a vertical tube, containing a floating substance such as cork dust or saw-dust, which sticks to an inner greased pole.
- 3 Non-returnable float gauges: a float is raised, usually within a transparent tube and is held in place by a ratchet at its maximum level.
- 4 Non-return valve gauge: water enters the bottom of a clear plastic tube through a non-return valve and a column of water to the height of the maximum water reached is trapped as the outside level recedes.

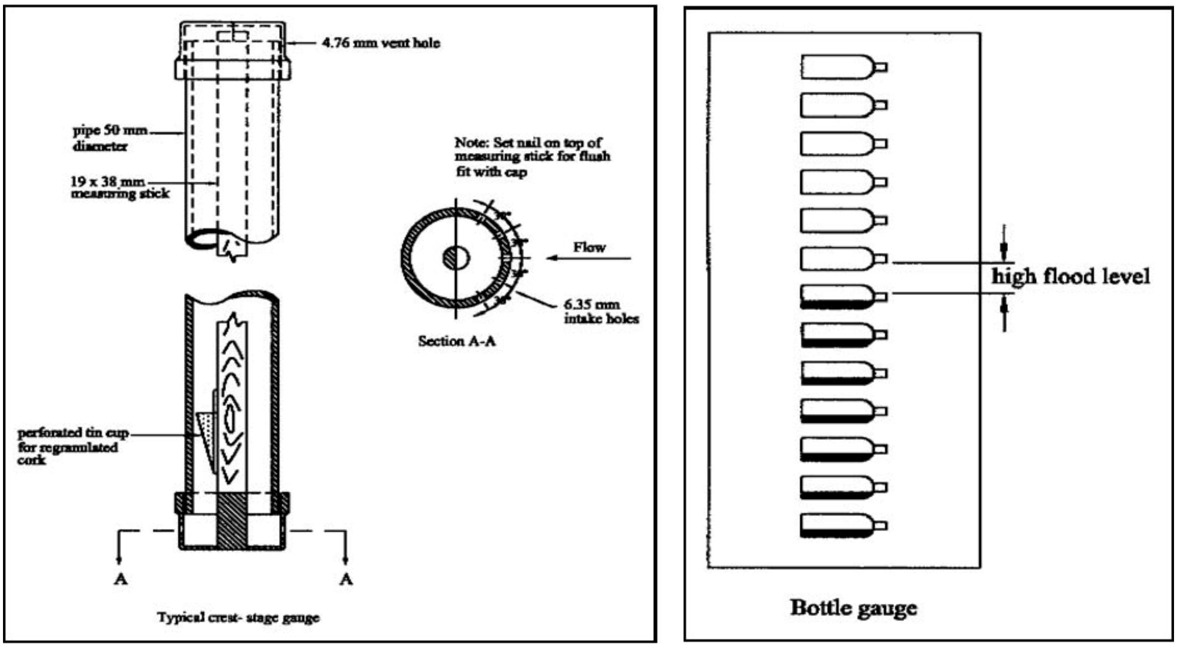


Figure 44 Maximum Flood Level (MFL) Gauge

The use of crest stage gauges upstream and downstream of the gauging site will provide important information on the slope of the water table during peak flow, which in turn is indispensable for proper extrapolation of the discharge rating curve. Its use is strongly recommended.

4.3.2.2.5 Float system with autographic recording

A float sensor consists of a float attached to a beaded wire or perforated metal tape (on sprockets), at one end, and, to keep the wire/tape taut, a counterweight at the other end. The wire or tape hangs around a pulley wheel. The system is specially engineered to prevent slippage to assure that the stage fluctuations sensed by the float are fully transmitted to the pulley. The movement of the pulley wheel drives a chart recorder, see Figure 45 Typical float, pulley and counterweight water level.

A float sensor requires to be installed in a stilling well to protect the float and to damp out oscillations. The stilling well is connected to the river by means of one or more intake pipe(s) or perforations to ensure continuity between the river and stilling well levels, see Figure 6.7.

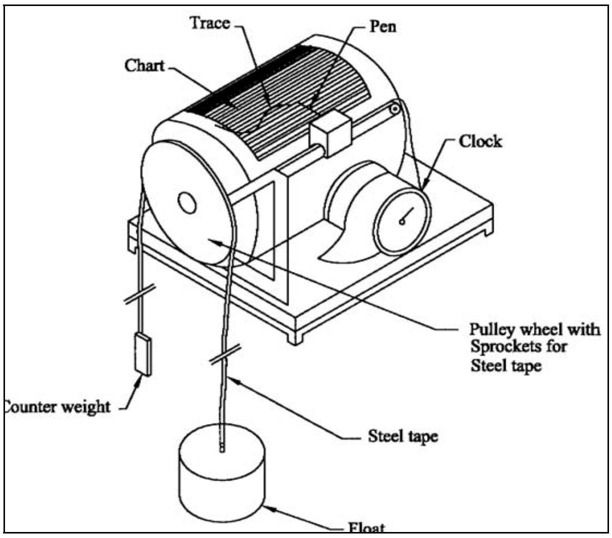


Figure 45 Typical float, pulley and counterweight water level

Hence the float sensor system with autographic recording comprises the following components:

- A stilling well,
- A float sensor
- An autographic chart recorder, and
- Staff gauges inside and outside the stilling well

Figure 46 float sensor in stilling well

The height of the structure is determined by the minimum water level one wants to record and the maximum flood level. The platform, carrying the pulley and recorder, should always be well above the maximum flood level to keep the equipment dry under all circumstances, whereas the distance between platform and the maximum stage is sufficient to allow the float to sense the highest stage. At the lower end there is generally more flexibility. The stage variation at the lower end is generally small and can well be taken from a staff gauge. By avoiding the lowest stages the intake of sediment is also reduced and it provides an easier means to clean the intake pipes when silted up.

The inlet diameter should be designed to balance the opposing influences of oscillation (small inlet required) and lag (larger inlet required). It is suggested that the inlet area to be 1/1000th of the area of the stilling well, i.e. an inlet pipe diameter, which is roughly 1/30 x well diameter if one pipe is applied. The inlet area should also be designed to balance the ingress of sediment with the practical problems of its removal, whereas the diameter of the stilling well should be large enough to allow free movement of float and counterweight.

Static tubes on the stream end of the intake pipes are often applied to reduce drawdown and super elevation effects caused by high velocities past the end of the pipe.

Siltation is the most serious problem in stilling wells. In rivers, which carry a heavy silt load, it is advisable to flush or clean wells after each flood. In other instances one or two flushings per year may be sufficient. There must be adequate equipment provision for stilling well maintenance. As a guide, one portable pump with accessories per 5 stations is usually sufficient for rivers with a heavy silt load. On other rivers one pump per 10 stations should be adequate.

FLOAT SENSOR

Careful balancing of the float and counterweight is required over the operating range. The operating range is linked to the float/weight size and the wire tape weight. The accuracy obtainable depends on the float diameter. More larger is the float diameter, more higher is the accuracy. Reputable manufacturers of this type of equipment will specify the combinations of sizes of float, counterweight and pulley arrangements for various level ranges and accuracies. These are to be used to achieve the desired performance. The pulley and recorder have to be installed on a fixed and stable platform or table, well above the maximum flood level.

For proper operation of the sensor in the stilling well it is of importance that:

- the water level in the well is the same as in the river,
- the well water level is error free transferred to the pulley.

For reasons of improper design and/or maintenance of the stilling well, the water level in the well may deviate from the water level in the river. Similarly, the sensor may work unsatisfactory due to e.g. slippage of the wire, mechanical problems, etc. A full list of possible errors is presented below under operational problems.

AUTOGRAPHIC CHART RECORDER

The autographic chart recorder, operating on a float and pulley based system provides a continuous trace of stage with respect to time on a chart. The movement of the pulley wheel is translated into a movement of a pen mechanism or the movement of the chart relative to a pen. A spring-wound mechanical or battery driven clock is part of the recorder. Data is extracted from the chart manually or by means of a digitizing table or tablet. Two types of chart systems are available:

- a) drum type, where the chart is fitted to a vertical or horizontal drum. The following systems are in use:
  - ✓ the pulley drives the drum and the clock moves the pen, and
  - ✓ the pulley moves the pen and the clock drives the drum (see Figure 47 Horizontal drum recorders)
- b) strip type, where a chart roll is clock driven from one spindle to another; the pen is moved by the pulley (see Figure 48 Float operated strip chart recorder).

Major difference between the drum and strip type recorders is that the latter can be left unattended for a longer period as the chart allows a longer record on a chart and/or can provide a better resolution. Drum type recorders require daily charts for flashy rivers to get sufficient resolution and weekly charts when the water level fluctuates slowly. Though the frequent replacement of the chart may look disadvantageous for the drum recorder, this is not necessarily so. The experience with the float sensor in a well is that the functioning of the system should regularly be checked anyhow, irrespective of the type of chart recorder.

On both recorder types, changes in water level activate a pen or stylus on the stage axis of the chart. Recording scales range from 1:1 to 1:50. Most recorders can now record an unlimited range in stage by use of a pen-reversing device or by unlimited rotation of the drum. Gearing should be chosen with respect to the expected range in level at the station to give adequate definition for extraction without crowding the chart with too frequent reversals or drum rotations.

Errors in the recorded level due to the recorder can arise from malfunction or incorrect setting up of the recorder and/or chart, clock and mechanical problems, see below under operational problems.

Figure 47 Horizontal drum recorders

Figure 48 Float operated strip chart recorder

Staff gauges are installed inside and outside the stilling well, both having the same zero datum. The standard reference gauge must remain the outside gauge as the level on the inside gauge may be affected by blockage of the stilling well inlet pipe such that both staff gauge and recorder are registering the same inaccurate reading. In this case, comparison of inside and outside gauges provides a check on the functioning of the stilling well.

OPERATIONAL ASPECTS

The float type sensor with chart recorder will provide an accurate continuous recording of the water level variation in the river if the design is correct and the system is well maintained. In view of a variety of operational problems, which may occur with the float sensor and its accommodation, it is required that the gauge is inspected daily. The clock of the recorder is to be checked as well as the recorded water level with the staff gauge inside and outside the stilling well.

OPERATIONAL PROBLEMS

Different operational problems can arise with this type of sensor (chart recorder). They are listed below. The problems with the sensor and housing and with the recorder are discussed separately.

The operational problems with the sensor and housing may be of the following kind:

- Sudden or rapid water level changes can cause wire slippage/tape sprocket jumps.
- Weight will catch onto the bottom of the instrument bench or floor of instrument house if the wire is too short.
- Weight submergence can cause errors since the tension in the pulley wire/tape will alter. It is not always possible to avoid this. However, whenever possible it should be avoided. Bottoming out of the counterweight on the base of the stilling well should definitely be avoided.
- Float lag may occur if the intake pipe or holes is/are too small a diameter or if it becomes blocked.
- Insufficient dampening of oscillations if the intake pipe diameter or size of intake holes is/are too large. Natural level oscillations and surges can result from rapid water level stages.
- Hysteresis effects may result from float, pulley and gear combinations.
- Mechanical inertia effects can arise with rapidly changing levels.
- Gear-train backlash effects can cause error due to gearing wear.

- Some float systems have additional guides and pulleys to redirect position of float or alter chart-recording scales, which can reduce sensitivity.
- Inadequate float diameter or badly matched float and counterweight.
- Tangling of float and counterweight wires.
- Float and counterweight reversed (pen driven in the reverse direction with respect to level).
- Kinks in float suspension wire or tape.
- Extension of the wire/tape due to temperature increases.
- Bridge and wall mounted stilling wells can vibrate at high flows.
- Build up of silt on the float pulley, affecting the fit of the float tape perforations in the sprockets.
- The stability of the mounting bracket or base is important. It is strongly recommended that the pulley and recorder are installed on a fixed and stable platform or table.

Operational problems with the chart recorder may be due to:

- Incorrect choice of gearing: the full range of water levels is not covered.
- Backlash in the gearing.
- Friction in the mechanism.
- Improper settings of the chart on the recorder drum or strip chart in the sprocket holes.
- Improper joining of the chart edges.
- Distortion and/or movement of the chart paper (humidity).
- Distortion or misalignment of the chart drum.
- Faulty operation of the pen.
- Clock inaccuracy, over-winding or failure to wind.
- Insects or other organisms in the mechanism or consuming the chart.

Accuracy

A float operated recorder can be expected to sense the level to an accuracy of 3 to 5 mm, which may reduce to 10 mm for the accuracy of extraction of data from the chart, depending on the gearing and scale of the pen trace for recording ranges of the order of up to about 3 m. However, it must be realised that this can only be achieved with a high standard of maintenance and adequate checking, based on thorough training. As the recording range increases then the accuracy will further reduce.

Advantages and disadvantages of float and chart type water level recorders

- Advantages - it is relatively simple to operate and maintain, is widely used, can provide an immediate direct reading of stage and provide a historic trace without requiring an external energy source.
- Disadvantages - it is a mechanical device and therefore subject to errors from changes in temperature, hysteresis and friction. Also, the resolution of the chart scales, depending on the arrangement selected are sometimes a limitation on accuracy, the pen wears out and ink depletion occurs. Other problems can occur if the pulley wire becomes kinked, the counterweight becomes submerged or if the wires become displaced on the pulley wheel(s). Its operation therefore requires much attention. The chart has to be analysed or digitised to extract the data for entry onto a computer. This requires manpower and is a potential error source. Last but not least, the overall costs of the float sensor (initial and maintenance costs) are large, primarily due to the stilling well requirement.

4.3.2.2.6 Float system with digital recording

A float sensor consists of a float attached to a beaded wire or perforated metal tape (on sprockets), at one end, and, to keep the wire/tape taut, a counterweight at the other end. The wire or tape hangs around a pulley wheel. The system is specially engineered to prevent slippage to assure that the stage fluctuations sensed by the float are fully transmitted to the pulley. The movement of the pulley wheel drives a digital recorder. The float sensor requires to be installed in a stilling well to protect the float and to damp out oscillations. The stilling well is connected to the river by means of one or more intake pipe(s) or perforations to ensure continuity between the river and stilling well levels. Hence the float sensor system comprises the following components:

- A stilling well,
- The float sensor
- A digital stage recorder, and
- Staff gauges inside and outside the stilling well.

The components 1, 2 and 4 are exactly the same as for the float system with autographic recording. These components are discussed here before. The only piece that differs is the stage recorder. Instead of recording the rotation of the pulley wheel on a chart it can directly be captured in digital format by a shaft encoder. Essentially a shaft encoder measures the angle of rotation, either incremental or absolute, see also Figure 6.10. The output from the shaft encoder is recorded on digital data loggers and can be shown on a LCD display.

The absolute encoder is able to signal exactly where its reference zero is located relative to the 3600 field of rotation of its shaft, to a required level of resolution. The shaft-mounted disk is of glass (or similar light-transmitting material), patterned into "tracks" that, according to a binary pattern that alternatively obscures and transmits light from one side of the disk to the other. Absolute encoders of good quality and fine resolution are very expensive.

The incremental encoder signals the fact that shaft rotation is taking place as a train of logic pulses. Predominantly the incremental encoder is a revolution counter but which when linked to an appropriate counting mechanism can be readily converted into a rotational positioning device. Apart from cost the incremental encoder has the advantage over the absolute encoder that by its associated up/down counter it can track changing level multiple rotations of its shaft. This is particularly attractive for hydrometric applications where a high resolution is often required over a large level range.

The Optical Incremental Shaft Encoder is the type most widely used in hydrometric practice, though some specific proprietary data logging devices prefer to interface with Optical Absolute Encoders, for reasons of battery longevity. Examples of free-standing and parasitic shaft encoders are shown in Figure 49 Basic features of the optical shaft encoder.

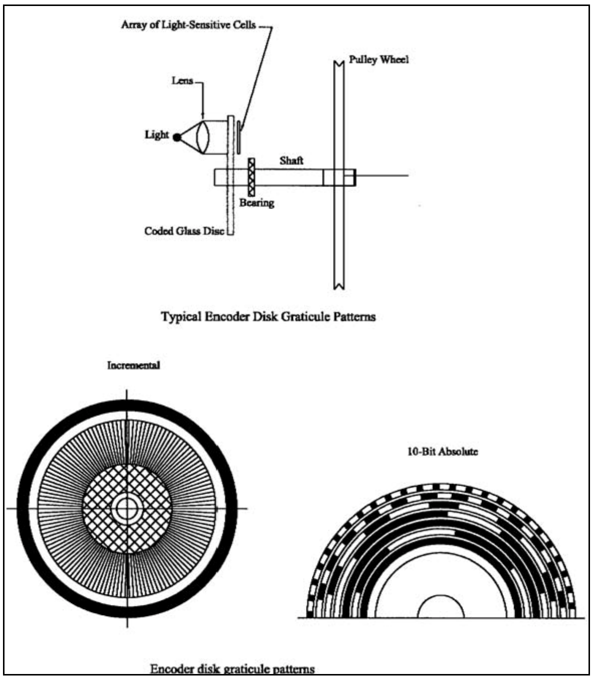


Figure 49 Basic features of the optical shaft encoder

ADVANTAGES AND DISADVANTAGES OF DIGITAL FLOAT-BASED WATER LEVEL RECORDERS

Advantages: - they can provide as good accuracy as the primary sensor i.e. the float system but do not have the errors associated with chart interpretation. For a well constructed float and pulley system they should be able to measure to +/- 3 mm. Shaft encoders can be added to some normal float and drum type water level recorders and as such, a back up chart can also be used in case of logger failure.

Disadvantages: -because they are operated by means of a float system they require the construction of a stilling well. Also, they can be subject to errors similar to those experienced with conventional float and chart recorders such as problems caused by submergence of the counterweight and line, displacement of the wires on the float or counterweight pulleys and kinks in the float suspension cables. Reference level adjustment is required when setting up, i.e. the shaft encoder has to be set relative to staff gauge zero, which may be lost during operational use. Accidental fast rotations of the pulley wheel cannot be tracked.

4.3.2.2.7 Pressure sensors (transducers)

The term pressure sensor is applied to devices, which convert changes in water pressure and hence water level into electrical signals, which can be recorded remotely from the point of measurement. A typical sensor consists of:

- 1 a mechanical force-summing device, perhaps a diaphragm or a bellows and resonating quartz crystal, which is displaced by the pressure head of water, and
- 2 a device which converts the mechanical displacement to an electrical signal.

The electrical signal is transmitted by a connecting cable to a solid state logger or to an associated interface for analogue to digital conversion before storage in the logger memory.

Gauging the water level by a pressure sensor does not require a stilling well, provided an electronic filter is applied to average out the pressure fluctuations due to turbulence. This makes the pressure transducer an attractive solution for water level gauging relative to a float sensor if no stilling well is yet available. An application is shown in Figure 6.12

The pressure transducer type DWLR consists of the following components:

- a pressure sensor
- a data logger with wave attenuation filter and power supply
- enclosure for pressure sensor and data logger:
  - ✓ either a submerged enclosure, where pressure sensor and data logger are integrated,
  - ✓ or an in-well enclosure, i.e. a submerged pressure sensor and a data logger above the water table
- a cable suspending the sensor
- a data retrieval system (Palmtop computer or Hand Held Terminal), and
- PC software.

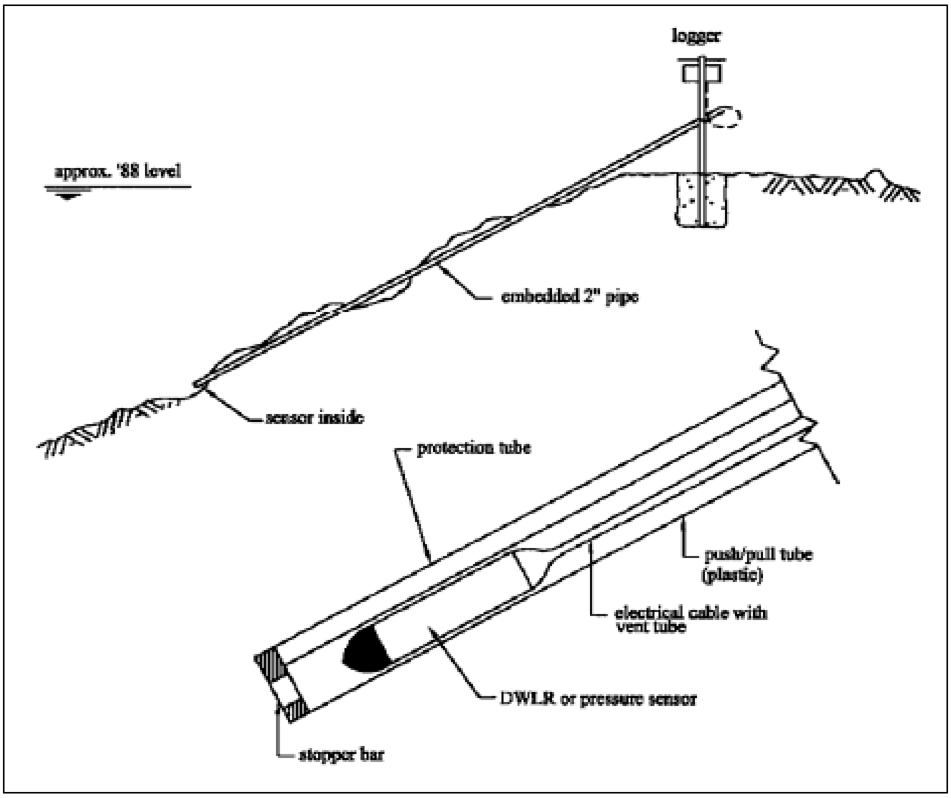


Figure 50 Water level gauging with pressure transducer

PRINCIPLES OF OPERATION

The essence of a pressure transducer is that a sealed diaphragm is deployed at the interface between the instrument's interior and "the outside world", see Figure 51 Schematic of absolute, vented and sealed gauge types.

This diaphragm is constructed so as to be sensitive to differences in pressure on one side relative to the other. Most present-day transducer designs make use of semi-conductors. In particular ceramic sensors are preferred which provide high stability, are not susceptible to fouling and are touchable. When there is a pressure differential, the diaphragm will distort (albeit minutely). The degree of this distortion will relate to the degree of pressure difference across the diaphragm, and should be relatively stable with respect to time and within achievable manufacturing tolerances. Some other device will be attached to the inner face of the diaphragm. This device will have the capability to translate the distorting movement of the diaphragm into a changing electrical characteristic. Appropriate electronic devices and circuitry may transform this, when suitably energised, into a varying electrical output, which may be processed for purposes of display or record. The processed data from the pressure sensor is normally stored on a data-logging device. Traditionally in hydrometric applications the logger has been remote from the pressure-sensing device, thus the need for the connection cable.

However, some modern sensors have the logging unit housed in the same housing as the pressure sensor.

At any given time (usually at manufacture), the device may be precisely calibrated. A mathematical relationship may be established between the external pressure being applied to the device's diaphragm, relative to the internal pressure within the device's body, and a measurable electrical output.

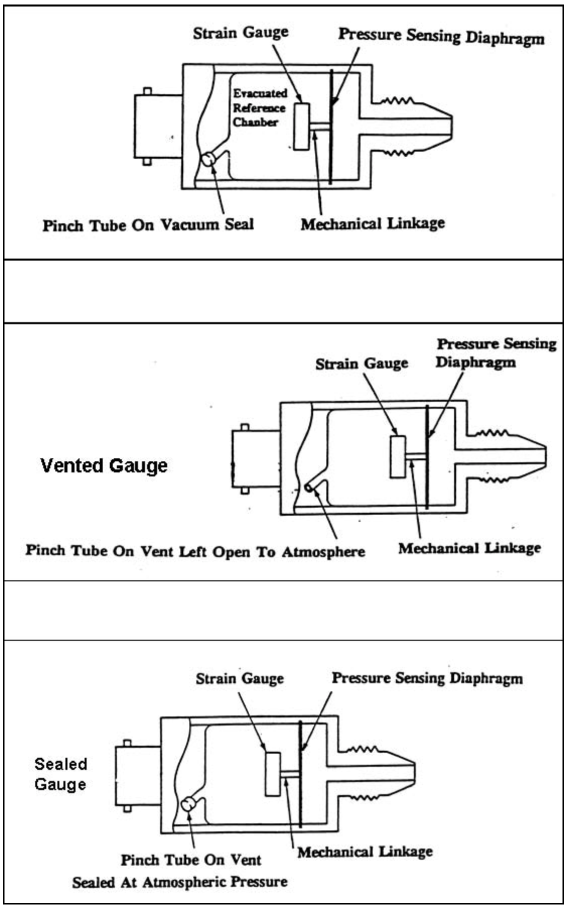


Figure 51 Schematic of absolute, vented and sealed gauge types

In all transducers, water pressure and hence level is measured with respect to one of three references; this reference gives the transducer classification:

- 1. vented gauge – reference to atmospheric pressure;
- 2. sealed gauge – a fixed known pressure;
- 3. Absolute gauge – vacuum.

Since all open channel flows are subject to atmospheric pressure, the vented gauge type is the most suitable for application to water level measurement. Ventilation is normally achieved by means of a flexible plastic tube that connects the interior of the transducer body with atmosphere, by way of the cable that also carries incoming electric power and outgoing signal conductors. The open end of this narrow gauge pipe is secured above water level and protected from condensation (e.g. using silica gel) and ingress of dust. However, blockage of the vent pipe through inadequate protection has been a recurrent problem with some sensors.

If an absolute pressure sensor is used it is necessary to adjust for atmospheric pressure. This normally requires the installation of another device above the maximum flood level in order to monitor changes in atmospheric pressure. One advantage of the absolute pressure sensor over the vented or gauge pressure type is the fact that if the logging device is installed within the pressure sensor housing there is no need to have a connecting cable carrying the vent tube to above the water surface.

The pressure sensor has the advantage of easy installation. Some protection of the cable on the bank side is essential and the transducer may be fixed in position in a perforated steel or PVC tube. However the installation cost is only a small fraction of the cost of construction of a stilling well and the equipment is only marginally more expensive than float based sensors. Additionally they will continue to operate when partly covered in sediment provided that the sensor's diaphragm is no touched by sediment. There is a power requirement for the transducer and interface in addition to the logger but typical dry cell battery life is at least several months.

Lightning strikes can be a source of danger to transducers and their associated instrumentation in particular long connection cables can 'pick-up energy'. Therefore, lightning protection is advisable taking the manufacturers' advice as appropriate.

ACCURACY

The accuracy of pressure transducers is usually expressed as a percentage of Full Range Output (FRO) or Full Scale Output (FSO) and is used to indicate that any given value of pressure (water level) sensed by the device may be expected to be accurate to within a stated percentage of the FRO value i.e. the calibration range of the device. Most of the better modern pressure transducers will have quoted accuracy's of 0.1% of FRO i.e. +/- 10 mm for a 10 m range transducer. This is acceptable for most hydrometric applications in Ethiopia (if there is no problem of sediment which is rarely the case). Higher accuracy transducers are available but these are considerably more costly.

SENSOR SELECTION

There are a large number of manufacturers, and products vary widely in their accuracy, repeatability and robustness for river water level measurements. Also, manufacturer's specifications can sometimes appear complex and can be misleading. Therefore, before deciding on a type of sensor it is advantageous to have some basic understanding of the terminology and the technology i.e. how to interpret a specification? In this regard a Glossary of Terms and other Information is presented at the end of this sub-chapter. Below the main criteria are presented. However, any system procured must have a proven record of performance for river level measurement under the environmental conditions it will be used in, or should undergo prolonged, thorough and independent field testing before acceptance.

The following are the main criteria necessary in the choice of pressure sensor

- 1. Pressure range. A transducer is selected whose permitted maximum over-pressure rating is in excess of the greatest head likely to be encountered at the measurement site.
- 2. Non-linearity. The deviation of a calibration curve from a straight line.
- 3. Hysteresis. The deviation between an ascending and a descending calibration curve
- 4. Span error. The deviation from a predetermined output change measured between zero and full scale pressure
- 5. Repeatability. The difference between the outputs at identical pressures during successive pressure cycles
- 6. Thermal zero and span shift. The effects of zero shift due to temperature changes within the operating range.
- 7. Long-term stability. The errors of zero and span as a result of thermal cycling.
- 8. Suitability for measurement in water. Care should be taken in transducer selection; its housing assembly and cable sheathing should be suitable for immersion in water to pressures at least 50% greater than the maximum pressures being measured. Suitable anchorage points require to be provided for cables liable to flexure.

- Beside the sensor, specifications for the data logger, enclosure for pressure sensor and data logger, cable, data retrieval system and software should be met, see Chapter 7. Special attention is to be given to ingress protection of the enclosure and cable assembly, and adequacy of the moisture blocking system to prevent condensation of water in the vent tube and in the sensor.

ADVANTAGES AND LIMITATIONS OF PRESSURE SENSORS

- Advantages: - they give a direct reading of depth, do not require a stilling well to damp out water level oscillations and are thus relatively easy and cheap to install even though some form of protection is strongly advised. The cable does not have to be installed vertically and transducers are ideally suited for interfacing with data logging systems.
- Limitations: - the levels of accuracy are typically limited to 0.1% of full scale, they are susceptible to changes in environment (manufacturer's stated accuracy is often at a constant reference temperature), they can be affected by changes in density of the water column, are some times susceptible to flow (velocity head) and electrical noise effects and are liable to drift over relatively short time scales (< 1 year).

4.3.2.2.8 Ultrasonic - in air (look down) water level sensors

INTRODUCTION

This technology senses the position of a water surface relative to a known datum by measuring the time taken for a pulse of ultrasound to travel from the sensor itself (which is the effective datum) to the water surface and back again to the sensor (see Figure 52 In air (look down) water level sensor -General Operating Principle). Its principle claimed operational attributes are that it is non-intrusive and non-contacting. A stilling well is not required for successful operation. Because such devices do not have to be deployed either in or on the water, installation can be straightforward and, hence, cost effective relative to alternative technologies.

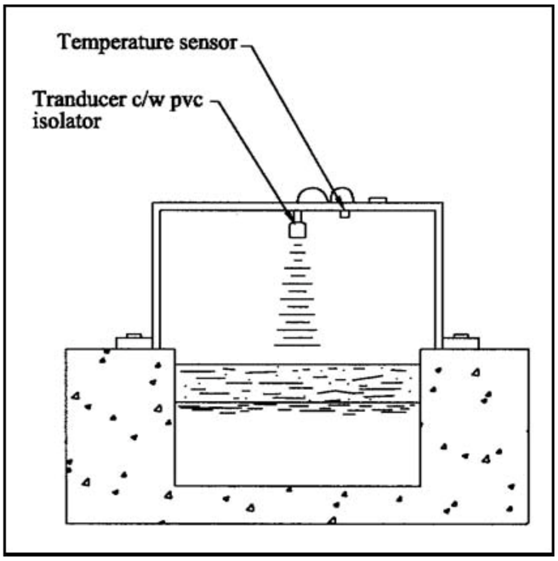


Figure 52 In air (look down) water level sensor -General Operating Principle

PRINCIPLES OF OPERATION

The basis of the technique is that, since the speed of sound in air is known (331.45 m/s at 0°C), "there-and-back" ("round trip") travel time can be equated readily with "there-and-back" distance. A constraint is that the speed of sound in air varies with density. Hence temperature and humidity affect the accuracy of the method. Corrections can be made for temperature changes. Therefore, in order to make allowance for temperature changes (1.7mm/oC/m change; warmer = faster), temperature compensation provision within the equipment design is required. Nearly all modern devices of this type do, either by direct temperature sensing or by "on-line calibration" in the form of a built-in reflecting target located at known distance from the transducer face.

Most (though by no means all) modern devices of this type claim sensing accuracy of the order of 1mm per meter range, with operation up to 3 m range in typical open air water level sensing applications. However, they have been used successfully over larger operating ranges (10 – 20 m).

The technique was developed originally for industrial applications and has been primarily used in environments with relatively small level ranges such as effluent discharge channels. Nevertheless, in principle, use of the technique could be considered for river-related applications in Ethiopia and has been demonstrated to work effectively in similar physical conditions. However, there are several operational limitations/drawbacks of the technique, which the user should be aware of:

- a) Temperature compensation

Effective temperature compensation may be problematic when there is a large air gap to be spanned between sensor and water surface. Also, such other variables as air humidity and wind effect can come into play - to the potential detriment of either measurement accuracy, reliability, or both. Wind can result in loss of echo reception, as well as being one possible cause of a varying temperature profile in the path of the ultrasonic beam. Conversely in some situations wind can be a possible advantage since it can destroy temperature stratification.

- b) Proportional Error Effect

The sensor measures the air distance between itself and target (the water surface). It then goes on to infer the variable of (normally) true interest, stage by subtracting the measured variable (air distance) from a known, previously-surveyed constant -the distance between sensor and the stage board zero. The outcome of this process, in terms of the Absolute Accuracy of Depth Determination, will vary quite significantly depending upon the ratio of air distance to water depth. With system accuracy expressed (as it normally is) as a percentage of Range (which is often called "Span" in related literature), and a range of water level to be accommodated that extends to (say) 6 meters, a device that is accurate to 0.1% of range will deliver a determination of water level location that is within +/- 6 mm. If, at a given instant, the water body in question is 5 meters deep, that depth will be inferred plus or minus 6 mm - an absolute accuracy of 0.12%. If, on the other hand, the true water depth is 0.5 meters, that value will be assessed still to an accuracy of plus or minus 6mm - an absolute accuracy now of 1.2%. More exaggerated water level ranges will result in more exaggerated accuracy relationships. Therefore, higher water levels can be measured more accurately than lower water levels. However, there is minimum distance within which water level cannot be sensed at all (See para. (c) below).

- c) Dead Band Effect

There is a minimum distance between ultrasonic sensor and water surface within which the water level cannot be sensed at all. This is usually known as the Dead Band. This is because, when the sensor is energized and caused to transmit a pulse of ultra-sound, it does this by vibrating and, even after electrical excitation has ceased, the sensor continues to vibrate for a finite period. Only an echo from the water surface that returns after the sensor has ceased to vibrate (or "ring"), and which itself has the effect of causing the sensor to vibrate and generate an electrical signal as a consequence, will be unambiguously distinguishable. Because of the Dead Band Effect, there is a system design compromise to be addressed where wide range excursion is to be accommodated. For any given claimed system measurement accuracy (1%; 0.5%; 0.1%, for example), best absolute accuracy of shallow depth measurement will be achieved by reducing the range over which the instrument is to operate. Reducing the range brings the sensor closer to the water surface and, inevitably, increases the risk of (possibly critical) data loss if the water level naturally encroaches within the Dead Band.

- d) Propagation Effects

The pulse of ultrasound that is generated by the Air Ranging device propagates as a cone which, at distance from its source may be wide enough to intersect channel banks or bridge abutments when water level is low - while performing acceptably when water level is high. A number of detrimental effects may result viz.:

- Spurious direct reflections, i.e. the sensor may range the obstacle rather than the water surface.
- Spurious indirect reflections (arriving late at the sensor head via a longer route than the most direct).
- On some sensor types, heavy rainfall may result in false echoes, and as a consequence give false echoes.

Also, there may be:

- energy dissipation to the extent that return signal detection is rendered uncertain.
- the way that surface water waves (e.g. ripples, wind waves, standing waves) are interpreted by the sensor will vary with range from the sensor to the water surface i.e. will the signal be reflected from peaks or troughs or an average of the two.

Ultrasonic level recorders have traditionally required mains power supplies owing to a higher power demand than other sensors. However, power requirements have been significantly reduced and the sensor is now a viable alternative at remote sites.

ADVANTAGES AND LIMITATION OF ULTRASONIC - IN AIR (LOOK DOWN)

The advantages and limitations of Ultrasonic - in air (look down) are:

- Advantages - the sensor can be mounted above the water surface, say from an extender bar (a bracket cantilevered outwards) attached to a bridge pier, they are therefore easy to install and maintain and are ideally suited for interfacing with data logging systems.
- Limitations -it is difficult to aim the acoustic beam tightly and thus transducer heads cannot be mounted flush with the side of the channels but need to be fixed on an extender somewhat. The compensation temperature sensor will only measure temperature at one place. Temperature gradients over the length of the ultrasonic beam will give rise to errors. Absolute errors will tend to increase the greater the distance from the sensor to the water surface.

4.3.2.2.9 Radar (electromagnetic) - in air (look down) water level sensors

Microwave sensors are ideal for use in moist, vaporous, and dusty environments as well as in applications in which temperatures vary. Microwaves (also frequently described as RADAR), will penetrate temperature and vapor layers that may cause problems for other techniques, such as ultrasonic. Microwaves are electromagnetic energy and therefore do not require air molecules to transmit the energy making them useful in vacuums. Microwaves, as electromagnetic energy, are reflected by objects with high dielectric properties, like metal and conductive water. Alternately, they are absorbed in various degrees by low dielectric or insulating mediums such as plastics, glass, paper, many powders and food stuffs and other solids.

Microwave-based sensors do not require physical contact with the process material, so the transmitter and receiver can be mounted a safe distance from the process, yet still respond to the presence or absence of an object. Microwave transmitters offer the key advantages of ultrasonic: the presence of a microprocessor to process the signal provides numerous monitoring, control, communications, setup and diagnostic capabilities. Additionally, they solve some of the application limitations of ultrasonic: operation in dust, temperature and vapor layers. As the cost of such sensor decreases rapidly, this technology is and will be very efficient for surface water level measurement.

Figure 53 Typical radar (RLS OTT) - in air (look down) water level sensor

4.3.2.2.10 Recommendations for the Water information and knowledge management project

Staff gauges are still today the reference for water level measurements, and then must be installed on all sites. For sites which required a permanent sensor, "Figure 54 Technical synthesis of water level sensor technology" gives informations on technology capability. Based on it, we confirm the choice done by the MoWR for giving preference to radar sensor technology.

	Float system	Ultrasonic in air	Ultrasonic in water	Radar	Bubbler pressure	Pressure sensor (piezoresisttive)
Precision	++	++	++	+++	+++	++
Reliability of the measurement	-risk of pipe obstruction by sediment	- influence of temperature, humidity on the air column	-	++	--	- electric hit (linked to the technology)
Energy consumption	++	+	+	+	--	++
Maintenance constraints (cleaning)	--	+	-	++	--	-
Maintenance constraints (equipment)	++	-	-	-	--	+
Installation constraints	in	+	-	+	-	-
Risk of destruction during floods	---	+	-	+	-	-
Atmospheric constraints	++	--	++	+	++	++
Risk of sediment obstruction	---	+	---	+	--	---
Adequate to flood management	+	+	+	+	+	+
(+ good – adapted)/(- bad- non adapted)						

Figure 54 Technical synthesis of water level sensor technology

4.3.2.3 Stage measurement techniques- Groundwater

The following section outlines various standards to which water-level measurements should adhere, to ensure a consistent level of data quality. Various types of water-level measurements can be made, and the standards vary with the type of equipment used to make the measurements.

4.3.2.3.1 Overview of groundwater water level techniques

All manual water-level measurements should be designed to have repeatable and accurate methods of determining the elevation of the water-level surface. Manual (or discrete) water-level measurements can be made by use of several methods, including the graduated steel or wetted tape method, the electric-tape method, the air-line method and recent non-contact methods, such as sound waves and radar waves.

The method one chooses to use depends on the conditions of the site (such as well construction, well diameter, depth of the well, and accessibility) and status of the water level (for example, flowing wells require different methods than nonflowing wells).

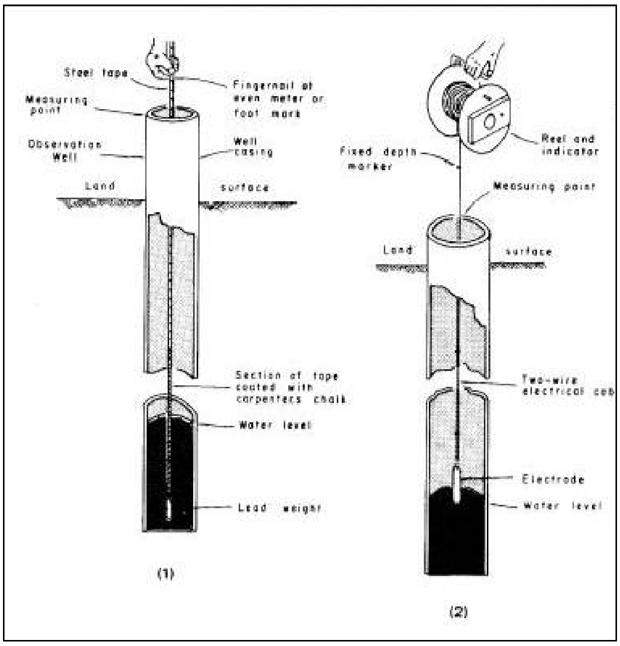


Figure 55 Different methods for manual groundwater level measurement

Two types of devices are available to measure groundwater levels. “Figure 55 Different methods for manual groundwater level measurement” show typical sounding devices.

A metal tape can be used to measure groundwater levels by inserting it between the well casing and pump column until it contacts water. The use of chalk on the lower part of the tape improves the visibility of the water line and helps verify that it has contacted the groundwater surface. The depth of water is then determined by subtracting the length of tape that was submersed in water from the total length of tape inserted in the well.

An electric well sounding device is a simple continuity detector. The length of cable lowered down the well when continuity occurs is then noted as the depth to groundwater.

4.3.2.3.2 Recommendations

Here after advantages and disadvantages of the different techniques.

STEEL TAPE

Advantages	Disadvantages
Accurate for many systems	Generally cannot be used for quick, repetitive measurements such as early-time in aquifer tests
Easy to use	Costs (~$1,400)
Robust	Need chalk to read
Considered most accurate method for measuring nonflowing wells	Hard to measure when water is dripping in or condensing on well casing
Easy to use	Not recommended for measuring pumping levels

ELECTRIC TAPE

Advantages	Disadvantages
Easy to use and read	Not as accurate or as robust as steel tapes
Can be used for quick, repetitive measurements	Need battery
Generally cheaper than steel tapes	Requires you to carry replacement/backup battery
Don't need chalk	

DATA LOGGER WITH PRESSURE TRANDUCER

Advantages	Disadvantages
Simplest and continual record	Requires maintenance, If battery fails, data may be lost
Immediate visualization of water-level fluctuations	Costs ((~$4,000)
Accurate and reliable	

Based on these tables, we proposed to user electric tape for manual measurement and, for automatic measurement, pressure transducers connected to a datalogger, even this equipment is expensive.

To protect the logger against vandalism, the Water Level Logger shall be simply inserted into the pipe (minimum 2" pipe diameter). The top of the logger shall rest on the top of the well pipe. The logger shall be concealed by a slip cap or a locking well cap. The Water Level Logger shall be adapted to larger or smaller well casings by using standard PVC pipe reducers and fittings. The cable length is extremely difficult to increase since it has internal vent tubing. In case of 2" or larger wells, the cable may be shortened simply by coiling it around a 1" diameter stick or pipe and securing it to the stick at both ends

4.3.3 Data Acquisition Equipment – CIM level 1

Data acquisition equipment shall be:

- a multi-channel configuration for surface water network, and will be called "Data Collection Platform" (DCP here after)

- a single channel configuration for groundwater network, and will be called "Logger" here after.

Another difference between these two kinds of equipment is housing, as the groundwater data-acquisition equipment housing shall not exceed the following dimensions: 4.8 cm diameter x 29.2 cm length, to be fit for insertion in a 2 inch well.

4.3.3.1 General

All sensors should be connected to a Data Collection Platform forming an "intelligent" data collection system and on-site data logger. The main advantages of such a system as compared to other solutions are:

- (a) Elimination of human error in the reading of instruments;
- (b) Minimization of gaps caused by observation failure;
- (c) Avoidance of errors in reading or digitizing from graphical recording charts or paper tapes;
- (d) Direct transfer of the digital data into electronic databases;
- (e) Modulation of the rhythm of data acquisition according to the dynamics of each of the variables measured and the real needs.

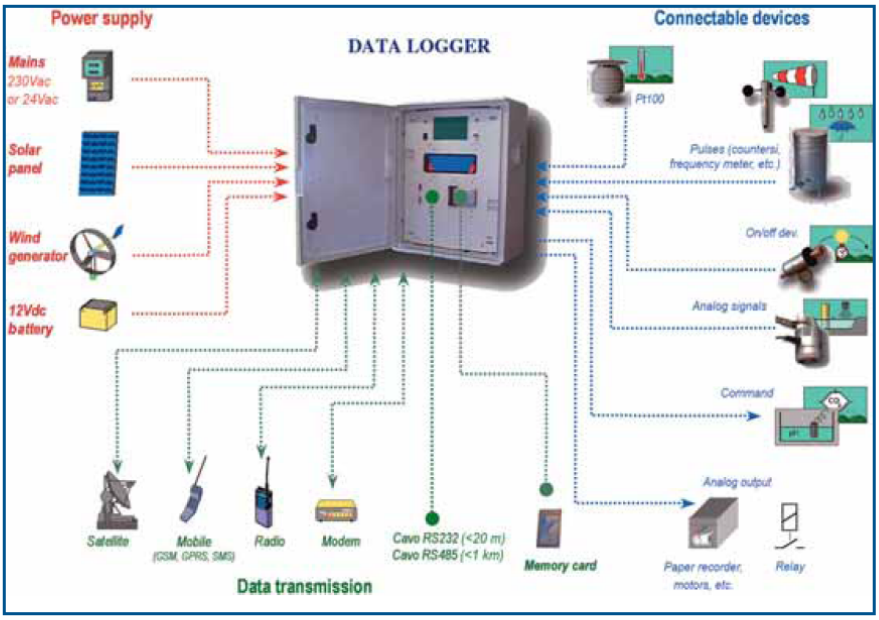


Figure 56 A Multi-purpose data logger and interfacing devices

4.3.3.2 Appropriate technology

Successful and sustainable Hydrometric system implementation requires the use of appropriate technology for a particular site. The instruments to be installed should be standard, simple, maintainable at a reasonable cost and appropriate for their intended functions, with a high level of demonstrated reliability and robustness.

Variations in climatic conditions and technological and infrastructure facilities available in the Ethiopia have to be given due consideration while selecting the project equipment.

Although, the utilization of modern equipment for monitoring must be promoted, with the resultant speedy access and dissemination of data, because of vandalism experienced in certain parts of the world, an alternative approach may be required. Threats to the performance of instrumentation may be classified as :

- (a) instrument failure;
- (b) natural hazards such as floods and lightning;
- (c) robbery or vandalism.

It must be realized that instrumentation is fragile and does not tolerate errors in installation or electrical coupling beyond its tolerable limits. The possibility of theft and vandalism should be considered when selecting instruments and the location of stations. The most successful protective measure to combat theft and vandalism is to deploy a local observer to watch over the station who also takes gauge plate readings at regular intervals as a crosscheck. Such control readings are useful as a quality check of the data.

Moving away from automated modern equipment and communication systems towards older or basic technologies, however, introduces greater levels of human intervention. It may also be difficult to implement such a system in very remote places, and human error in readings may affect the quality of data and slow down data transmission. Although not desirable, this is more acceptable than a vandalized system with complete data breakdown. It is, therefore, recommended to give preference to the utilization of modern technology, with recourse to older or basic technologies being made only when equipment security is a major concern.

4.3.4 Data Transmission System: CIM level 2

4.3.4.1 Data transmission in real time

Stations should transmit data in near real time if the primary objective of the network so dictates and should therefore be equipped with an appropriate transmission system. The transmission of data in real or near real time is a prerequisite for the early warning and management of floods and accidental pollution events.

Satellite technology has the greatest advantage despite the initial capital outlay for the equipment. The latest advances in instrumentation in terms of low power consumption are very attractive. However, it may be appropriate to point out that the choice of telemetry is not necessarily related only to the degree of urgency of data required at the receiving point. Two other functions of telemetry have to be kept in mind while making the choice. One of the main reasons for using telemetry is to secure and speed up data transmission and to permit remote monitoring of the status of the condition of the instruments and the Data Collection Platforms, thus reducing the requirement for regular visits for data collection. The system should be selected to best meet needs and to cope with the ground conditions and available infrastructure.

4.3.4.2 Data transmission in near real time

It is important to note that data transmission from the field to the national control centre need not necessarily be in real time. For certain normal operational purposes, such as the management of dams and hydroelectric plants, near-real-time data may suffice. The table above lists various technologies, which may be considered and evaluated for use in a water management project for obtaining data in near real time. These options range from a very basic system, utilizing the services of an observer who can also operate as a flood warning officer, to more advanced satellite-based systems.

Technology	Equipment and installation costs	Cost of maintenance and operation	Reliability during floods	Form of data at point of measurement	Advantages/ disadvantages and comments
Observer and flood warning officer	Negligible (gauge plates and communication medium)	Salary of observer	Acceptable	Analogue	The officer fulfils two important duties
Landline telephone	Low	Low	Not acceptable	Analogue/digital	Prone to breakdowns during floods
Radio	Expensive (repeater stations required)	Medium to high(technician for maintenance required)	Risky but acceptable	Digital	Lightning protection compulsory. Theft and vandalism
Cellular telephone	Low	Low	Risky	Digital	Prone to overloading. Emergency channel required. Theft and vandalism
Meteosat burst	Very expensive	Medium to high(technician for maintenance required)	Acceptable only for very large catchments	Digital	Requires master stations and service provider. Theft and vandalism
Satellite	Expensive	Low	Acceptable	Digital	Theft and vandalism

A basic system, if considered appropriate for the primary objective of the component, may be considered for incorporation into a Hydrometric system if other communication means for the transfer of data from the field to an operational centre are not available. In such a case, the data will have to be converted from analogue to digital form at the centre. The main disadvantages of such a system are reliance on the human element and a large delay between measurement and final use or archiving. Ancillary advantages of such a basic system are the creation of human works, duality of reasonable responsibilities of the observer (data capturing and flood warning officer) and protection against vandalism and theft.

4.3.4.3 Fundamental principles of data transmission

It is often necessary to connect equipment and systems which are separated by distances from several meters to thousands kilometers'. "Telemetry is the techniques used for transmitting and receiving information (in the form of analogy and digital signals) through physical medium, the protocols used to structure the communications in an orderly manner for accessing multiple sites and methods for interfacing between communications mediums and the data acquisition systems". Great number of DCPs can be hooked up to a single master station, and several single master stations (called sub-muster stations) can be "interconnected and then brought back to a central processing location".

When one accesses, controls and sends this information between different sites, this is called data acquisition. Data Collection Platform (DCP) is a combination of on-line monitor/device, sensor, and transducer together with all transceiver and communication interface equipment, places locally on the monitoring site. Combination of telemetry and data acquisition forms the basis of SCADA. Current development of data telemetry allows the end users in water treatment and water distribution utilities to use the most suitable for their needs method/methods for reliable delivery to a central computer of field information about chemistry of drinking water.

Methods for data transmission can be broadly classified as *landline* and *wireless*. Landline systems incorporate the following widely used systems:

- Leased and dial-up phone systems;
- Fiber optics systems.

Wireless technology for data transmission was used for the development and implementation of the following systems:

- radio systems;
- microwave systems;
- satellite systems;
- mobile phone systems;

All these methods of data transmission have found successful applications in remote water quality monitoring, health data monitoring, meteorological, seismic and geological data transmission, etc.

4.3.4.3.1 Landline data transmission

The telephone lines used to carry most of the voice and data communications consist of a pair of thin-diameter insulated copper wires (called twisted pairs). The wires are twisted around each other to minimize interference from other twisted pairs in the cable. Twisted pairs have fewer bandwidths than coaxial cable or optical fiber. There have been the standard communication channels for voice, data and information, but are now diminishing because of more reliable media such as coaxial cable, optical fibers, microwave, or satellite.

A cable connects a master site with DCP. Usually, cables are placed in the ground, conduits, or on the ground surface. The cost of cabling and associated labor heavily depends on the distances over which data transmission is required. Another way of cabling is to use public telephone network line (PSTN Public Switch Telephone Network). In this case, a computer via a modem dials the DCP's phone number (or vice-versa), and establishes communication for data transmission. Providing there is access to a public telephone network lines, this method can be cheap compared to all other means for data communication. The cost of the telephone connection can be increased when digital connection to DCP is needed.

Leased phone (included ADSL technology) and dial-up phone lines do not require significant expenses; however, they suffer from very to medium expensive operation, respectively, in the long run. The operational cost depends on the length of telephone lines and the amount of data transmitted. At the same time they can be used for short and long distances. The reliability of leased phone lines is good, however for dial-up phone systems it highly depends on the overall quality of public phone system; and when modern modems are used, data throughput is relatively high for leased phone lines and poor for dial-up phone systems. When leased phone lines and ADSL) are used, data from remote locations can be transmitted in the *continuous* mode, and only in the *event* mode in the case with dial-up phone systems.

Among landline modes of data transmission, fiber optical lines have separate specifications. A fiber-optic cable consists of tubes of glass through which data are transmitted as pulses of light. Although a fiber- optic cable is diametrically smaller than a human hair, it has 26,000 times the transmission capacity of twisted pair media. A major advantage of fiber-optic media is its high level of security. These communications channels are not susceptible to electronic interference. Therefore, they are a more reliable form of data transmission compared to other landline options. Fiber-optic cables are also significantly less expensive than coaxial cable. A disadvantage of fiber-optic channels is that they cannot carry information over great distances (excepted installing expensive relays).

As these technologies are not available on site, they will be not proposed.

4.3.4.3.2 Wireless technology

RADIO TRANSMISSION

Among all types of data transmission, radio transmission is the most widely used due to the following major advantages[4]:

- depending on the frequency band, remote telemetry unit can be placed kilometers from the central computer;
- there are few restriction as to where DCP should be placed;
- cost associated with installing cables is not involved.

When choosing the frequency band the following issues should be addressed: distance between sites, terrain type, data speed required, equipment availability, required system integrity, application, and frequency availability and licensing requirements.

Radio modems usually are used when there is need for replacement of wire lines to remote sites. They provide computers and Data Collection Platform (DCPs) with a transparent communication over a radio link without any specific modification of a system. Propagation of high frequency radio signal should be in a free line-of-sight between transmitting and receiving antennae for reliable communication. The distance over which a radio signal can be transmitted decreases with a decrease in available power and with an increase in radio frequency. When power of radio signal is low or the land topography does not permit the line-of-sight data transmission, then repeaters are employed for receiving and retransmission of radio signals. This increases system costs and add vulnerable links whose failure can disable the entire communications system. Radio modems can be used in point-to-point and point-to-multipoint modes. The first mode operates in continuous radio frequency and non-continuous format. The second mode operates with only master and one of the modems at a particular time.

VHF – UHF - SSF

Radio modems which operate in Very High Frequency (VHF), Ultra High Frequency (UHF) and Spread Spectrum Frequency (SSF) radio frequency bands require medium expenses for their implementation, are inexpensive in operation, and have moderate to high data throughput. The process of data transmission is of medium reliability. These systems are very versatile in terms of mode of data transmission possible. They can perform continuous and event data transmission. The advantages of these systems which utilize the third type of frequency band, over the first two, is their insensitivity of radio frequency interference. However, the first two systems can be used for direct point-to-point data transmission over longer distances (of up to 30 km, and even further of about 150 km when repeaters are employed) over only from 20 to 30 km in the case of systems utilized SSF radio frequency band. The major drawback of telemetry systems, which operate in VHF and UHF radio frequency bands, is difficulty in obtaining free frequencies (from 80, 150, 430, 870 MHz) from local government authorities, versus ease in obtaining permission to operate systems in SSF frequency band (very often such permission in not needed at all, as in the case with 2.4 GHz license-free band).

Face to the large perimeter of the project, the radio technology in VHF, UHF et SSF will not be proposed.

HF

Actually, the MoWR is using HF radio for transmitting by voice, information relative to floods. HF High Frequencies (between 3 and 30 MHz) can be envisaged for data transmission on the perimeter of the project. As the ionosphere often refracts HF radio waves quite well (a phenomenon known as sky wave propagation as shown in Figure 57 sky wave propagation (HF propagation)), this range of frequencies is extensively used for medium and long range radio communication.

However, suitability of this portion of the spectrum for such communication varies greatly with a complex combination of factors:

- Sunlight/darkness at site of transmission and reception
- Transmitter/receiver proximity to terminator
- Season
- Sunspot cycle
- Solar activity
- Polar aurora

When all factors are at their optimum, worldwide communication is possible on HF. At many other times it is possible to make contact across and between continents or oceans. At worst, when a band is 'dead', no communication beyond the limited ground wave paths is possible no matter what powers, antennae or other technologies are brought to bear.

An experience has been done in Morocco (2002-2003), using HF-SSB for transmitting data in a flood alert context. Linked to the different meteorological constraints explained here before, this solution has been stopped face to the bad result, and the difficulties to operate efficiently the automatic network.

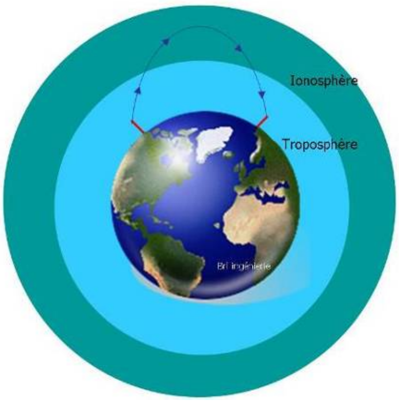


Figure 57 sky wave propagation (HF propagation)

MICROWAVE TRANSMISSION

When there is need for high-speed transmission of data from DCP to a central computer and back, the microwave (frequency band from 3 to 50 GHz) technology is used for data transmission at distance of up to 30 km. Application of repeaters can increase these distances. Microwaves are high-frequency radio waves that can only be directed in straight lines. Consequently, microwave transmission is usually limited to communications occurring within the limits of a particular city or community. For microwave transmissions to be able to occur over larger distances, data messages must be relayed from one location to another, using antennas placed at high altitudes usually twenty to thirty kilometers apart.

Data transmission systems utilizing microwave technology give high data transmission and reliability, both in continuous and event data transmission modes over long distances. These systems should be designed very precise, therefore, the cost of their implementation is very high as well as the cost of their operation. For these reasons, they are out of discussion in the present report. Secondly, face to the large perimeter of the project, this technology will not be proposed.

GSM/GPRS

Even GSM is the most popular standard for mobile phones in the world, the coverage in Ethiopia is very limited to the major urban zones of the country.

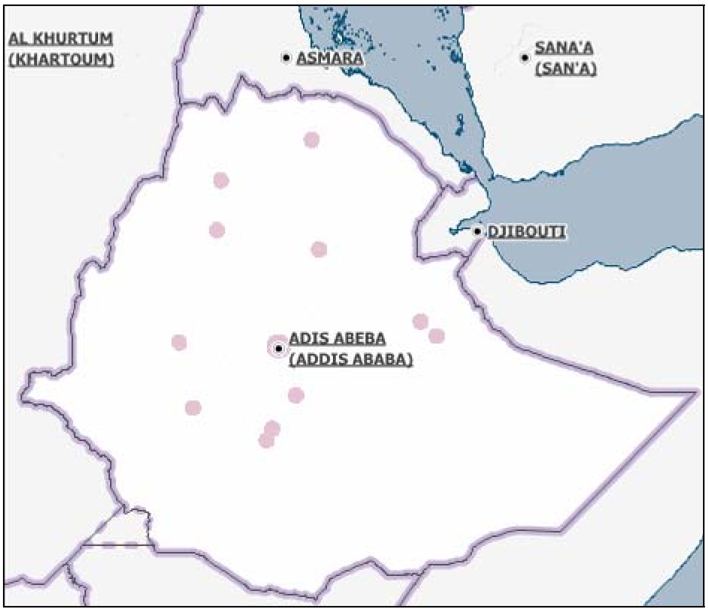


Figure 58 GSM Coverage in Ethiopia

SATELLITE TRANSMISSION

Satellite data transmission systems play an important role today and in the future. This technology is quickly establishing itself as one of the major data communication technologies, and provides reliable high-speed data transmission in areas where other methods of data transmission cannot perform adequately to the needs. "When this technology is employed, the scale of data transmission expands from local to regional and global". This method of data transmission is used when remote sensors are located at distances greater than 50 km. Instead of antennas, satellites can also be used to transfer data from remote data collection sites to another location. In such a case, the satellite operates as a repeater – data collected from remote sites can be transmitted to a communications satellite which then retransmits the data to ground stations for processing and dissemination to users.

There are two basic types of satellites which are used for data collection and retransmission, namely: *polar-orbiting* (altitude of about 870 km) and *geostationary* (altitude of about 36000 km). Satellite transmission stations that can both send and receive messages are known as earth stations (see Figure 59 Wireless data communication network utilizing satellite system).

In the case of a polar orbiting satellite system, all data from remote sensors *1* via data acquisition modules *2* are stored in *a platform transmitter terminal* (PTT) *3*. This terminal transmits these data to the satellite *4* when "it passes over a site", and the duration of transmission is less than a second at 100 to 200 seconds intervals. When geostationary satellite system is used the unit for data collection and transmission is called a *data-collection platform* (DCP) *3* with a data collection intervals from 15 to 30 minutes, and transmission intervals varied from 3 to 4 hours. The data from satellite are transmitted to a receiver *5*, which sends data to control centre computer *6*, for example.

In some situations satellite data transmission has a major cost advantage over traditional land-based networks. One advantage is that unlike the cost of land-based networks, such as microwave and fiber cable, the cost to provide services via satellite does not increase with the distance between sending and receiving stations. These systems cover medium to very large distances for data transmission. A major advantage of satellite transmission is that large volumes of data can communicated at once, or data can be transmitted on the continuous basis. A particular drawback of several disadvantages is bad weather can severely affect the quality of satellite transmissions. Another one is that it has a serious security problem, because it is easy to intercept the transmission as it travels through the air. The satellite transmission systems provide greater flexibility to the user, however, the price of such system and its operation is higher compared with other methods for data communication (radio, landline). However, with further technology progress, satellite data transmission cost is constantly decreasing.

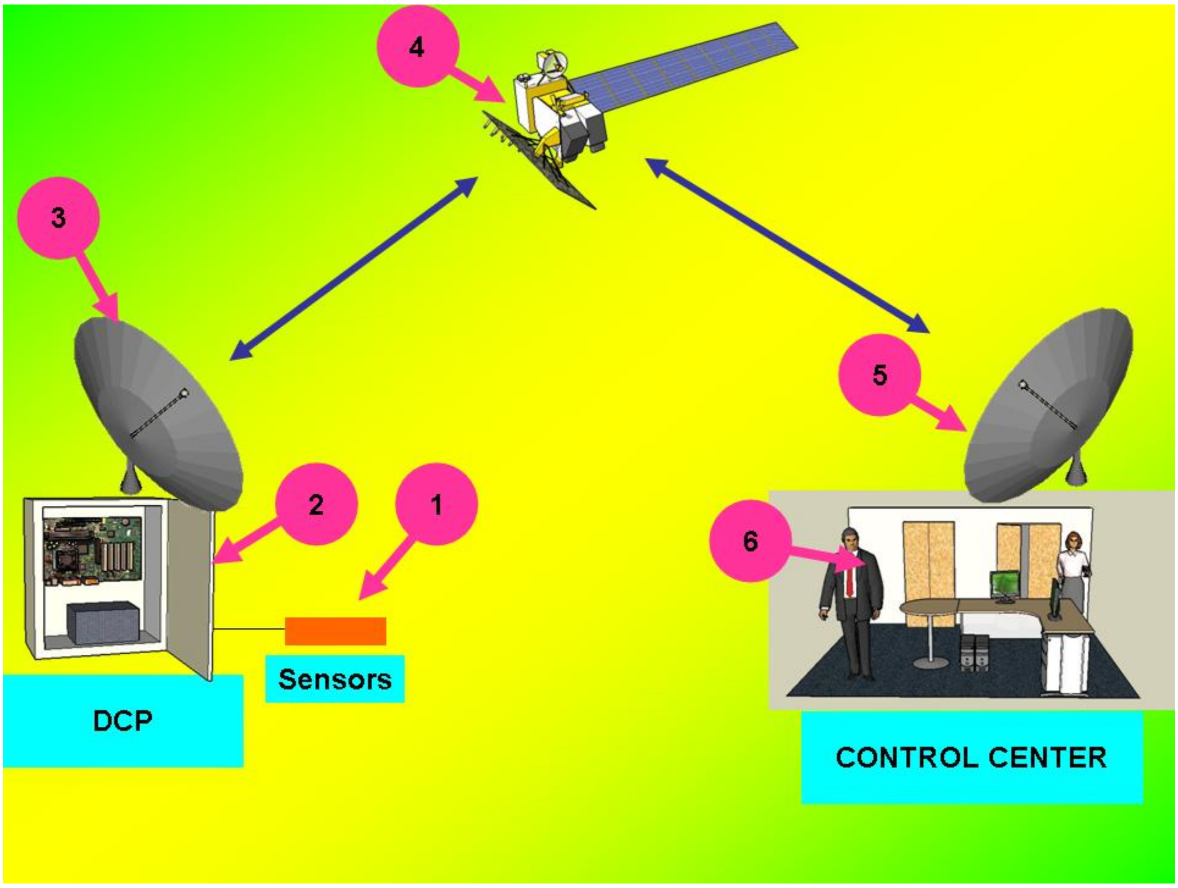


Figure 59 Wireless data communication network utilizing satellite system

METEOSAT

Initially, we have envisaged the design of the hydrometric network in the WHYCOS program context. The World Hydrological Cycle Observing System (WHYCOS) is a WMO program aiming at improving the basic observation activities, strengthening the international cooperation and promoting free exchange of data in the field of hydrology.

But a feasibility study has been proposed in 2004 to the IGAD institution. The Intergovernmental Authority on Development (IGAD) is an intergovernmental institution, bringing together Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan and Uganda, with the long-term goal of promoting sustainable economic development in its member countries.

As clearly described in the study, the major aspect of the project was to reinforce the regional infrastructure for data collection, transmission, storage and retrieval, by installing a network of about 50 data collection platforms (DCPs). These DCPs transmit data in near real-time using METEOSAT satellite from remote areas to a regional centre and the respective National Hydrologic Services. The major interest of this technical is choice, is that data transmission is free of charge, if the data are fully and freely disseminated to the neighboring countries.

All the identified HYCOS stations in Ethiopia are in the Awash River Valley.

1. Awash at Melka Kunture
2. Mojo at Mojo
3. Awash at Hombole

4. Kebena at Kebena
5. Awash below Koka Dam
6. Kelete near Sire
7. Kessem near Awara Melka
8. Awash at Melkasedi
9. Borkena at Bridge
10. Mille at Mille town
11. Awash at Adaytu
12. Awash at Tendaho
13. Awash at Berga

Since surface water is of such importance in Ethiopia, the feasibility study suggests that groundwater resource monitoring or climate observations will not be carried out in the project.

As the confidentiality can not be warranty, and face to the lowest number of sites selected, we suggest eliminating the METEOSAT solution.

IRIDIUM

The Iridium satellite constellation is a large group of satellites used to provide voice and data coverage to satellite phones, pagers and integrated transceivers over Earth's entire surface. The constellation requires 66 active satellites in orbit to complete its constellation and additional spare satellites are kept in-orbit to serve in case of failure.

Figure 60 Iridium satellite constellation

Ethiopian Telecommunications Corporation (ETC) provides Iridium satellite telephone service for working out side the coverage of either fixed or mobile telecommunications services in Ethiopia. The tariffs (without VAT) are:

- Sim Card USD$ 182.70
- 300 min calling card USD$ 404.80

Based on our needs, the time duration for each station will be enough for one year if we consider one transmission every three or four days.

Another solution will be to use a specific service (Short Burst Message) available on Iridium services, and completely dedicate to Telemetry system (as our hydrometric network). By comparison, the SBD service for a water level station (one transmission per day) should be closely to 500 USD $ (Tariff in France). If necessary, the contractor in charge of the implementation of the hydrometric network will have to define the service with ETC.

Note that ETC proposes also the Thuraya satellite solution, but retrieve data from the operator hub is less reliable and more complicates. For these reasons, we have preferred Iridium.

VSAT solution

VSAT (Very Small Aperture Terminal) is a service available at ETC. VSAT is a two-way satellite ground station with a dish antenna that is smaller than 3 meters. Most VSAT antennas range from 75 cm to 1.2 m. Data rates typically range from 56 Kbit/s up to 4 Mbit/s. Yet, the cost for using these services is not compliant with the management of a large hydrometric network as envisaged in the project. This service must be considered for connecting regional offices to the central office in Addis Ababa.

At short terms, ETC can use the Regional African Satellite Communications (RASCOM) infrastructure to develop its national traffic. RASCOM announces a “per minute” cost of national telephone communication, less than USD $0.10, and small satellite terminals with a price closed to USD$ 1400 per unit (two-way telephone booths).

In 2009, RASCOM satellite is in service but a commercial visibility limited to 2012, as its own satellite has been launched in 2007 with technical difficulties. A new satellite is under construction and will be launched in 2011.

4.3.4.4 Recommendations for the Water information and knowledge management project

	PSTN	GSM/GPRS	Radio HF	Radio xHF	Satellite METEOSAT	Satellite IRIDIUM	Satellite VSAT
Adaptation to project perimeter	--	--	-	--	+	++	++
Two-way communication (up stream – down stream)	++	++	++	++	++	++	++
Availability (in real time mode) of the communication infrastructure	--	++	++	++	++	++	++
Reliability of the communications face to lightning	+	-	-	-	+ band C	+ band L	-- band Ka
Reliability of the infrastructures face to floods	--	++	++	++	++	++	++
Risk of saturation of communications during crises	--	-	++	++	++	++	++
Reliability and security of information transfer	--	+	+	+	+	+	+
Confidentiality of the information transfer	++	++	-	++	--	++	++
Management and remote maintenance of DCPs	+	+	--	--	++	++	-
Low energy consumption	++	+	-	-	-	+	-
Small dimensions of the equipment (terminal and antenna)	++	++	-	-	-	++	-
Modularity and standardization of interfaces (hardware and software)	++	++	--	--	--	--	++
Acquisition cost of equipment	+	+	-	-	--	+	+
Operation cost of the solution	+	+	++	++	+++	-	-
(+ good – adapted)/(- bad- non adapted)							

Figure 61 Technical analysis of transmission media

For sites which required a real time transmission (or pseudo real time / 1 communication per day), "Figure 61 Technical analysis of transmission media" gives informations on technology capability. Based on it, we propose to use IRIDIUM satellite for communication.

4.3.5 Supervisory system: CIM level 3

Design of the Control Center (CC) will be organized around two communication front-ends which handle management of communications between various computer applications at the Control Center (CC) and the outstations. These communication front-ends handle communication management, data reading and writing toward the various items of equipment connected to them. They make up the core of the CC application. For this reason, front-end design must allow to easily take into account increases in the quantity of equipment connected, increases in data flow relayed through them, and connection of different types and brands of equipment.

The communication front-ends handle data exchanges with outstations via the telecommunication network (CIM Level 2).

Computer applications in the CC shall be mainly of two types:

- Real-time applications (level 3), working chiefly on the latest value of each data item transmitted from the on-site equipment.
- Delayed applications (batch processing) (level 4) working on logged data.

To handle real-time applications, workstations and server hold the supervisory/control application which handles the man/machine interface between on-site equipment and CC operators.

The supervision software shall allow operators to visualize outstations alarms and water level information in the form of animated mimic screens or views. These mimic screens shall be composed of a static background on which dynamic animations are overlaid.

As Regional and Central Offices will have access to it, the CC architecture will be Web technology based.

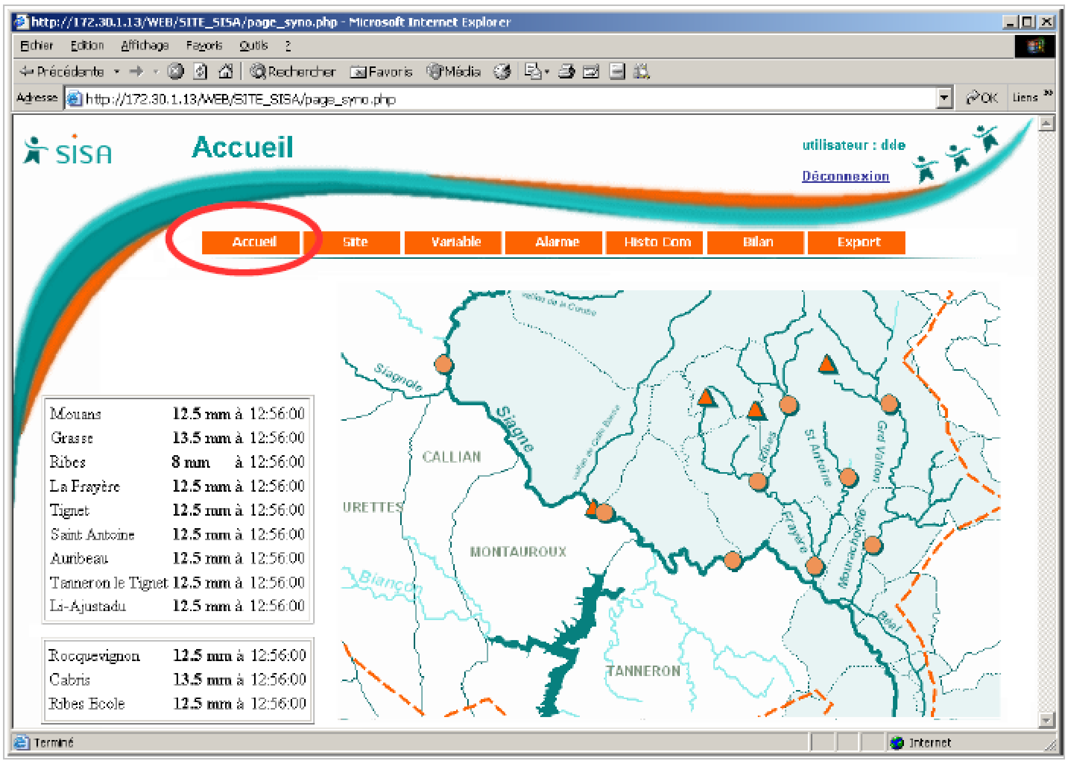
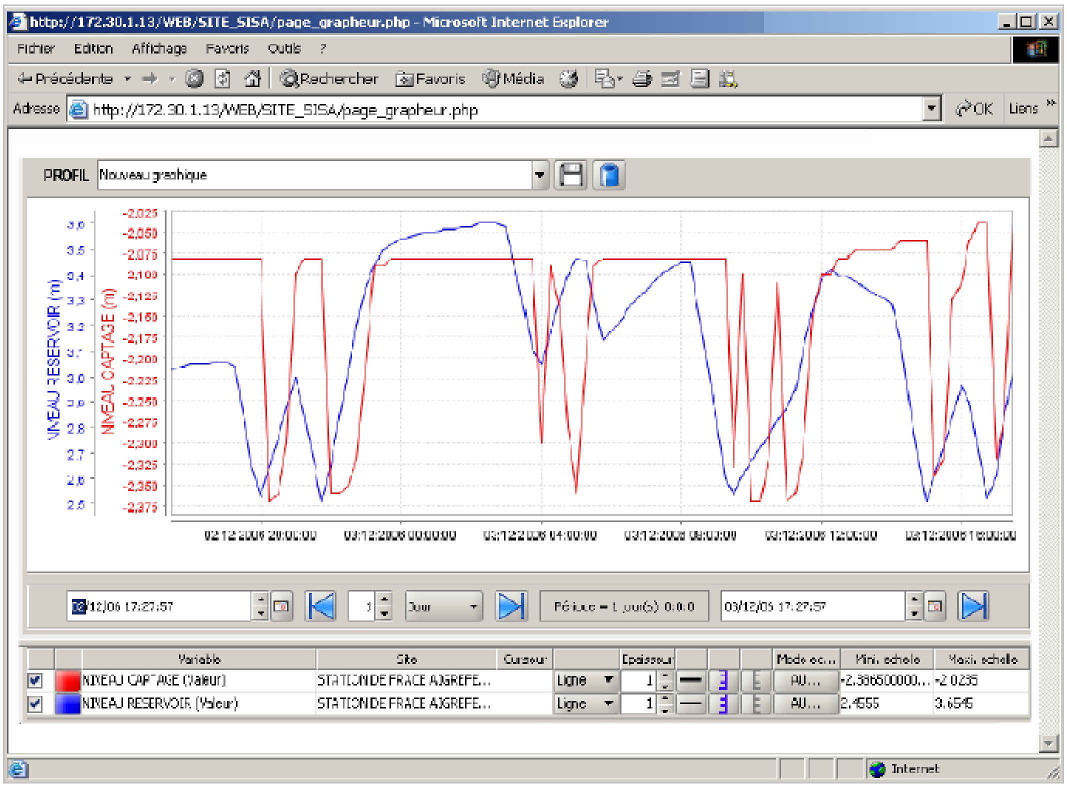


Figure 62 supervision software : mimic screen examples

Curve function available in the supervisory system will displayed on a time length, selected parameter such as water level, rainfall Curves will be updated automatically with the incoming new data value.



<u>**Figure 63 supervision software : Trends screen examples**</u>

The supervisory system will also manage operator acknowledgement of alarms. At any time, the operator may consult the list of current alarms, whether acknowledged or not.

<u>**Figure 64 supervision software : Alarms screen examples**</u>

4.3.6 Management data processing: CIM level 5

Planning of water resources projects requires adequate information on the hydro-meteorological regime. Poor availability of comprehensive and good quality data often leads to unsound design and operation. The existing systems in many countries including Ethiopia are inadequate in terms of reliability, accessibility, compatibility, and presentation.

The main causes are manual processing of voluminous information, a wide gap between the tools available and employed, and involvement of number of offices and agencies often lacking desired integration. A comprehensive computerized hydrological database linked with a geographic database is a basic requirement for efficient water management.

To improve the hydrometric network, a developing hydro meteorological information system for surface water and groundwater will be available in various regional branch office of the MoWR.

This will assist in gathering reliable and spatially intensive data on the quantity and quality of water of hydro-meteorological, hydrological and hydro-geological systems, and in utilizing computerized databases for planning, design and management of water resources systems.

Adequate facilities will be built up for proper storage, archival and dissemination of data. Infrastructure and human resources development aspects are emphasized and ensured for the sustainability of such a system, which should keep pace with the developments in technology and at the same time in hydrology and allied sciences.

- This level is described in a specific chapter hereafter:” Data Processing and Analysis”.

5. Data Processing and Analysis

5.1 GENERAL

In the following chapters, we have given a name to the water database system dedicated to process and manage water measurement. Closed to the name of the project, we proposed to call the system as **WInKS** for "**Water Information and Knowledge management System Project".**

The existing system of manual or partially computerized data processing is being replaced by "WInKS", a fully computerized data processing using dedicated and user-friendly software, including GIS support, to visualize and analyze spatial data.

The WInKS processes, stores and disseminates groundwater as well as surface water data but, data collection and specific process are dedicated to surface and groundwater. Then description will be done separately, however there is a overlap in the principles of data management.

Surface water data entry and processing are carried out almost exclusively by computer. Processing of hydrological data is not a single step process. It is carried out in a series of stages, starting with preliminary checking in the field, through receipt of raw data at Sub-divisional offices and successively higher levels of validation, before it is accepted as fully validated data in the State or Regional data storage centre.

The progress of data from field to data storage is not a one-way process. It includes loops and feedbacks. The most important link is between the field station and the lowest processing level at Sub-divisional offices with frequent feedback from both ends but there will also be feedback from State and Divisional offices downward on the identification of faulty or suspect data through validation. Facilities for feedback from data users must also be maintained.

Processing and validation of hydrological data require an understanding of field practices. This includes the principles and methods of observation in the field and the hydrological variable being measured. It must never be considered as a purely statistical exercise. With knowledge of measurement techniques or regime of a river, typical errors can be identified. For example for river level or flow, a long period at a constant level followed by an abrupt change to another period of static level would be identified as suspect data in a natural catchment but possibly due to dam operation in a regulated river.

5.2 DATA PROCESSING PLAN

Processing activities in each Regional Office and Central Office will be accomplished at two levels. A layered system of this sort may be described as distributed in contrast to a centralized system where all the resources are concentrated in a single or a small number of large centers.

Layers are as follows commencing from the lower end:

- At Regional Office, data are received from field stations and the bulk of data is entered and undergoes primary validation.
- Central Office receives data from all Regional Offices where final validation, completion and reporting of data is done.

The project area and the network of observation stations to meet the needs of the area are very large as is the resulting volume of data. There is a danger that staff will be completely overwhelmed with the tide of data.

To ensure that this does not occur, a workable plan has to be established for efficient management of data. Staffs who operate the Hydrological Information System and particularly managers must understand who does what, where, and how the levels are linked.

5.3 Distributed data processing – Advantages and Disadvantages

Data processing activities under WInKS will be accomplished at two levels. There are Advantages and Disadvantages of this approach and these are discussed here.

5.3.1 Advantages of distributed data processing

- Logical distribution of huge amount of data processing work for the whole region at several Regional offices ensure that adequate attention will be paid to all the aspects of processing resulting in the improved data quality. This is also, in general, commensurate with the present staff availability in different offices and leads to an optimal solution.
- Data entry operations and subsequent primary validation at Regional offices is carried out under direct supervision and by the staff who are supervising the observational activities regularly. The equipment and observational conditions together with the feed back from the field staff is fresh in the minds of the Regional staff and will be highly beneficial in carrying out primary validation.
- Inconsistencies in the observed data sets can be identified with a short gap of time (maximum of a month) after the observation is made by undertaking primary validation at the Regional offices.
- Feed back to the staff at observational stations with respect to any inconsistency found in the data set can be given very quickly and efficiently and subsequent corrective measures can be initiated thereafter.
- Staff involved in observation and supervision from the Regional offices, feel associated with the data being produced by getting involved in the data entry, primary and secondary data validation process. This will ultimately help in improving the quality of data.
- The possibility of omissions and mistakes is reduced since in the multi-layered processing plan the data is validated at more than one place.
- An increased level of accountability in the system is ensured, as the activities of one Regional office will be reviewed at higher levels.

5.3.2 Disadvantages of distributed data processing

- Since data processing activities are scattered in a very large areal extent it requires greater resource and effort to operate and maintain the necessary software and hardware. This aspect is not real for a Web architecture.
- The effort required in co-ordinating and fine-tuning various activities at several Regional Offices is far more than required for carrying out the entire processing at one place.

5.4 Data Processing activities at various levels

The activities at the Regional Office include:

- Receipt of field data in manuscript and/or digital form and maintaining a record of its receipt,
- Entry of field and digitized data in computer files and carrying out primary data validation,
- Additional automatic digitization of analogue records from strip and drum charts,
- Feed back to the field stations in case of discrepancies found during checking and for delays in receiving the field data,

- Transfer of data by Winks to the Central Office and maintaining a record of the transfer, and archiving of original field registers (pertaining to current three years) with proper documentation.

The activities at the Central Office include:

- Validation, correction, processing and compilation of field data relating to the water component of the hydrological cycle, including, precipitation (if available from another network), streamflow, sediment transport and water quality parameters
- Hydrological analysis as is required for the thorough validation of the data and for preparation of yearbooks, reports and documents.
- Preparation of yearbooks, reports and documents in tabular and graphical format.
- Dissemination of information (yearbooks, reports and documents);

5.5 FUNCTIONS AVAILABILITY AND COMPUTER FACILITIES

The type and amount of data processing activity to be carried at various types of Offices require varying configuration of hardware and software. A complete checklist of the features available in each of these modules is given in Figure 65 Availability of functions in different locations.

Features	Sub-features	Regional Office	Central Office
Data Entry and Editing	Space Oriented Data maps of basin features basin descriptive data hydraulic infrastructure	No	Yes
Data Entry and Editing	Location Oriented Data Observation stations Hydraulic structures Time Oriented Data Equidistant time series Non-equidistant time series Relation Oriented Data Profile measurement data Concurrent Observations Relationship parameters	Yes	Yes
Primary Validation	Listing of Data Test on Extremes Test on Timing Errors Inspection of Temporal Variation Inspection of Cross-sectional Variations	Yes	Yes
Secondary Validation	Checks on Physical & Chemical Consistency Inspection of Longitudinal/Spatial Variation Test on Relations Double Mass Analysis Nearest Neighbour Check	Yes	Yes
Hydrological Validation	Rainfall-runoff Simulation	No	Yes
Data Correction & Completion	Time Shifting of Data Interpolation Regression	Yes	Yes
Flow Measurements	Discharge Computations Fitting of Rating Curve Shift Adjustment Validation of Rating Curve Extrapolation of Rating Curve Stage-Discharge Transformation Hydraulic Computations	Yes	Yes
Sediment Data	Sediment Load Computations Fitting of Sediment Rating Processing of Reservoir Sediment Data Validation of Sediment Rating Extrapolation of Sediment Rating Sediment Transport Computations	No	Yes
Data Compilation	(Dis-) Aggregation of Series Series Transformation Creation of Derived Series Computation of Areal information	No	Yes
Statistical Analysis	Statistical Tests Basic Statistics	No	Yes

Features	Sub-features	Regional Office	Central Office
Data Reporting	Fitting Frequency Distributions Correlogram Analysis Spectral Analysis Range and Run Analysis Flow Duration Curves Frequency Curves Standard outputs primary used for validation purposes Customised tabular and graphical Outputs for preparing reports	Yes	Yes
Data Archive•	Data archive utilities	No	Yes

Figure 65 Availability of functions in different locations

The following hardware will be available at different types of data processing centers:

- at the Regional Offices, two personal computers together with an ink-jet and a laser printer and a DVD/CD Writer.
- at the Central Office, 4-6 personal computers with a network server together with laser printers, plotter (A0), digitizer (A0), scanner (A3), a DVD/CD Writer, suitable back-up and other essential peripherals.

5.6 AVAILABILITY OF STAFF AT VARIOUS LEVELS

The following staff will be available for carrying out various data processing activities at various data processing centres:

- at Regional Office:
  - ✓ One Regional Office for data entry and assistance job
  - ✓ One assistant hydrologist (and hydro geologist) for carrying out primary data validation will be available.
  - ✓ The functioning of the Regional data processing will be ensured by the Regional Office manager.
- at the Central Office:
  - ✓ Two data central office assistants for data entry and assistance job
  - ✓ 2-3 hydrologists (as per the amount of work) for accomplishing organization, final data validation, compilation and reporting activities will be available.
  - ✓ 1-2 hydro geologists (as per the amount of work) for accomplishing organization, final data validation, compilation and reporting activities will be available.
  - ✓ Support of water quality, database and information technology expert will also be available at the office.
  - ✓ The overall functioning of the Central Office will be ensured by the Central Office manager.

5.7 TIME SCHEDULE FOR DATA PROCESSING AT VARIOUS LEVELS

Maintenance of strict time schedule for all the data processing activities at various Offices is of utmost importance. The time schedule for the completion of activities at various data processing centres is as given below:

- at the Regional Offices :

- ✓ The data of any month from all the observational stations falling under its jurisdiction are required to be entered and primary validation completed by the 10th of the following month.
- ✓ The field and processed data sets along with the primary validation report for each preceding month must leave for regional office by the 10th of every month.
- ✓ However to ensure that data processing work is distributed evenly over the whole month, data will be forwarded from the field three times per month in ten day periods. This will also ensure that the entry and primary validation activities will not be rushed through at the last moment.

- At the Central Office
  - ✓ Both field and fully processed and validated data will be held at the Control Centre
  - ✓ Field data sets will be received by the 10th of the following month in which the data have been collected.
  - ✓ Fully processed and validated data will be received by the 15th of the following month and made available for general dissemination. Only under exceptional circumstances will validated data from the Central Office be retrieved for correction. An example would be where gauging in an exceptional flood shows that previous extrapolation of a rating curve has been incorrect, thus requiring reprocessing of some extreme flood discharges.

5.8 DATA PROCESSING

5.8.1 General

Data processing entails transforming the raw data into forms that enable ready manipulation and efficient storage for prospective users. Data typically enter the system via key punching of manuscript records, by mechanical conversion of analogue records, or in a digital form. Raw data are commonly compressed or reformatted into their most usable forms, and they should be subjected to a variety of quality checks at appropriate stages.

Regardless of the type of data being processed or the path that its processing takes, a basic requirement is to maintain a standard of operation that will not degrade the quality of the data.

The processing system should be integrated, and it should be reviewed periodically to ensure its continuing effectiveness in the light of new systems, technology, and data user requirements. Some elements that should be considered are noted briefly below.

The system should aim at minimizing duplication of effort, avoiding unnecessary processes, monitoring progress and completion, and ensuring that interrelated activities are coordinated effectively. The system should be structured to include checks at appropriate stages. It should encourage broad patronage by allowing rapid, easy access to the data, and it should be geared to update data at routine, short intervals.

The system should have sufficient flexibility to allow easy correction, addition, or upgrading of faulty sections of the data. At the same time, it must be protected by a high level of security to ensure that any alterations to the database are legitimate and authorized. All original versions of a data set, plus the corrected version, should be archived. This allows the pedigree of any set of data to be checked.

At a more technical level, great care should be taken in setting up the computer algorithms for data compaction, computation, and checking. They have a direct effect on the quality of the stored data. Once in place, algorithms tend to be taken for granted, and an inadequate routine can degrade the database for long periods of time without detection. Similarly, any enhancements to the software should be dated and documented after testing to assist tracing periods of incorrect processing. For a more concise presentation, the various components of a complete data-processing system are shown below.

Data processing							
Data preparation	**Data entry (input)**	**Prequalification / Validation**	**Primary processing**	**Database updating**	**Secondary processing**	**Retrieval**	**Output**
Prepare punching documents by: ■ Transcription Field notebook entries Non-standard data formats ■ Coding Reduction/ standardization of input data	Punching document: 1. Direct keying through VDU 2. Charts and maps Direct input by digitizer 3. Computer compatible media a. Disk or USB memory b. Communication lines (hydrometric data)	■ Range checks ■ Sum checks ■ Inter-station consistency checks	■ Standardization of units ■ Calculation of derived parameters ■ Further coding of input to reduce storage requirements ■ Arranging data in database format	■ Add new data sets to existing database ■ Report any errors	■ Programs for routine reports ■ Statistical summaries ■ Infilling missing data values ■ Interpolation or aggregation of data	■ Selection of data by: a. Parameter type b. Parameter value c. Location d. Period of record e. Time interval of record ■ 2. Selection of output device	■ 1. Printers ■ 2. Plotters ■ 3. Screen ■ 4. Computer storage media ■ 5. Telemetry
	Error correction						

Figure 66 Components of data processing

5.8.2 General processing procedures

A somewhat artificial distinction has been made between validation procedures and primary processing procedures for presentation purposes. Data-validation procedures essentially make comparisons of test values against the input data. Primary processing has been viewed as the procedures necessary to manipulate and transform the input data for output and storage.

From an operational point of view, both validation and primary processing are part of the master database updating procedures executed on a monthly basis in most hydrological systems. However, it should be noted that both updating and some stages of primary processing, are conditional upon the successful validation of data.

The main components of primary processing are:

- Data adjustments for known errors: these are the errors reported by the field technician or those persons responsible for manual quality control of the incoming data sets. The most common adjustments required are compensation for datum errors and differences between the time and date recorded and those logged by the field technician for control purposes. The errors may be associated with gradual drift of the clock, sensor device, or recording mechanism, but may also be caused by discrete events, e.g., clock stoppage or pen/punch jam. In the former case, the processing system may automatically perform the required adjustment using linear or more complex scaling of recorded values. In the latter case, it is normal for manual estimates of missing data to be provided if the affected period is not too long and if sufficient background information is available. The reporting of errors should entail the use of standard procedures and standard forms for reporting errors to data-processing personnel. The form may be used for noting corrections to stage or flow. An essential feature of the correction process, whether performed by manual or computer methods, is that all modified data should be suitably flagged to indicate all adjustments that have been made;

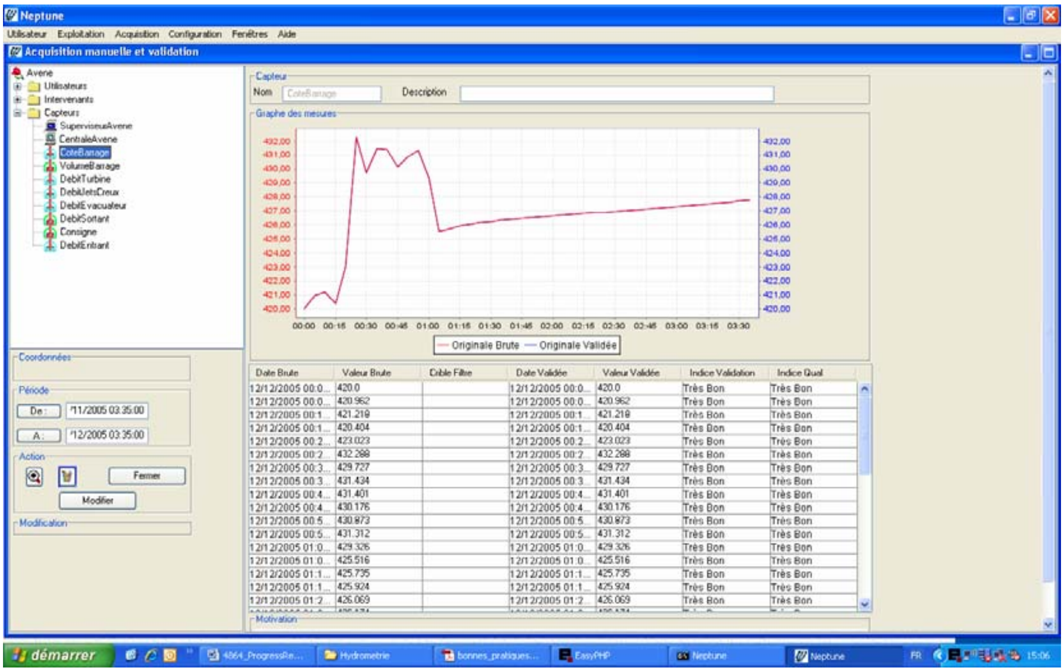


Figure 67 Validation tool example

- Aggregation and interpolation of data — Many variables, because of their dynamic nature, must be sampled at relatively short periods, but are only utilized as averages or totals over longer periods. Thus, for many hydrological applications, climatological variables may be required only as daily values, but must be sampled with greater frequency to obtain reliable daily estimates. Temperature and wind speed are good examples, but, in many cases, the same is true for water level and river-flow data. While aggregation is straightforward for constant interval time-series, a two-stage interpolation/aggregation must be made for irregularly sampled variables. It is important to note that the levels of data aggregation are usually different for data output and data storage purposes. Data at a high level of aggregation, e.g., monthly and annual averages, may then be kept permanently on-line for general reference purposes. Interpolation and aggregation need to be performed in space as well as in time. Cross-correlation of station records to estimate missing data is a common spatial interpolation, and the estimation of areal values from point observations is a common form of aggregation;
- Assessment of derived variables: The most frequently derived variables are runoff and potential evapotranspiration. However, the full range of derived variables is very broad and includes many water quality indices. One important database management decision is whether derived variables need to be stored after they have been estimated and reported. It is obviously not essential to occupy limited storage space with data that may be re-computed from the basic data held. The basis for making this decision is:
  - ✓ How often will the derived variables need to be retrieved?
  - ✓ How complex are the computations required, both in terms of the algorithms used and the amount of background data required?
  - ✓ Are the objectives of the database to store basic data for users to process themselves, or to compile inventories of all important (basic and derived) variables?

The original data series should be preserved, preferably on a stable long-term storage facility. Derived variables, particularly those derived from two or more basic time-series, may themselves need validation. Thus, while both the river-stage and rating-curve data may satisfy any validation tests applied to them on an individual basis, their combination to produce flow estimates may reveal some inconsistencies.

- Output of statistical summaries: These are the routine outputs, usually on a monthly and annual basis, of data processed during the database updating cycle. These outputs may also be considered as the basic data retrieval outputs and, with this in mind, many elements of the primary processing and data-retrieval software should be common.
- Conversion to database storage formats:
  - ✓ In addition to the re-grouping of data, additional levels of data coding may be performed and measurement units may be converted to the standards adopted in the database. The conversion of irregular to regular time series is also one of the operations necessary in many cases.
  - ✓ Not all data would be subject to each of the above processing steps. The degree of processing necessary depends upon the particular hydrological parameter; the way data were recorded and/or abstracted for data entry, the type of processing system, and the ultimate purposes of the collected data. In real-time systems, it is quite conceivable that incoming data in the raw state are all that is required to trigger some management or operational action.
  - ✓ The extent of processing also depends upon the severity of data-status flags and reports produced during the data validation phase. Unless the validation system detects an indisputable error, i.e., failure to satisfy an absolute-error check, it is preferable to allow processing to continue, maybe even to the updating stage. Such a policy eliminates the need for any further processing action should the queried data prove later to be correct. The status of the data is flagged while confirmation or editing of the data is awaited;

5.9 DATA ANALYSIS

5.9.1 Analysis of Water Level Data

Water levels of rivers do basically not form a homogeneous set of data, suitable for statistical analysis. A water level in a river is the result of an upstream discharge and the hydraulic conditions of the downstream control, i.e. the hydraulic characteristics of the control channel and in case of backwater a downstream water level. For a river with a flood plain one will observe that a fixed increase of discharge at stages where the river flows in bank will produce a much larger increase in the water level than when the river flows over bank; in case of a very wide flood plain the levels will hardly rise in response of an increase of discharge, as depicted in "Figure 68 Response of river stage to fixed increase of discharge for in bank and over bank flow".

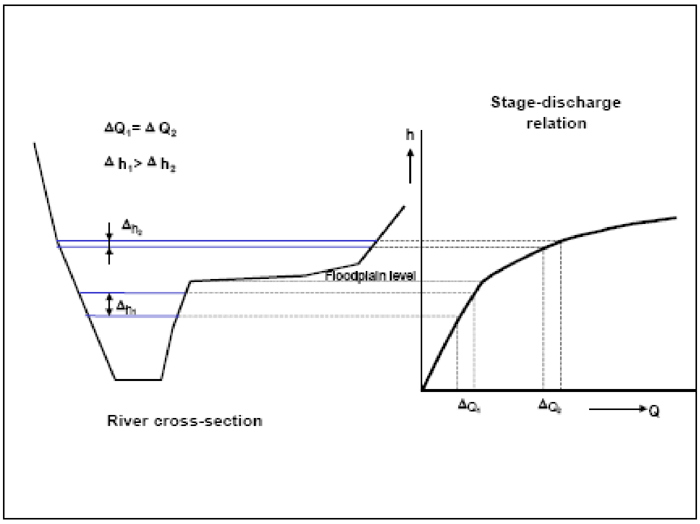


Figure 68 Response of river stage to fixed increase of discharge for in bank and over bank flow

5.9.2 Analysis of Discharge Data

The purpose of hydrological data processing software is not primarily hydrological analysis. However, various kinds of analysis are required for data validation and further analysis may be required for data presentation and reporting. Only such analysis is considered in this chapter. Analysis will be carried out at Regional Office. There is a shared need for methods of statistical and hydrological analysis with rainfall and other climatic variables. Many tests will be briefly summarized here after:

- computation of basic statistics
- empirical frequency distributions and cumulative frequency distributions (flow duration curves)
- Time series analysis
  - ✓ moving averages
  - ✓ mass curves
  - ✓ residual mass curves
  - ✓ balances
- regression/relation curves
- double mass analysis
- series homogeneity tests
- rainfall runoff simulation

5.9.3 Analysis of Quality Data

This chapter presents aspects of data analysis that are relevant to the surface water quality data collected. It is prepared for water quality specialists in the Regional Offices and Central Center, who are responsible for analyzing water quality data compiled from different external laboratories. While data analysis is done for multiple purposes, and many different types of analyses are possible, we will focused only on the data analysis needed to produce a standardized yearbook for surface water and ground water quality. This chapter doesn't concern an overview of all the possible tests and analyses that can be done for water quality data.

5.9.3.1 Validation objectives

Validation and screening are important first steps in data processing. The WInKS will offer a range of tabular, graphical, computational and statistical validation techniques for these purposes, such as:

- plotting of time series
- identifying and flagging of outliers;

Various options are available for series completion. Among these are interpolation techniques which use series relations derived with e.g. regression techniques or spatial relations. Much emphasis has been given to facilities for administration of the data processing steps and data qualification features. The latter include assignment of labels to individual data indicating the source - e.g. original or corrected - and reliability of data.

Screening of data aims at detecting outliers. An outlier can be defined as an observation that does not matches with the pattern of earlier observations. Outliers may be the result of mistakes in the data generation process but could also be an indication of a true change in the system under study, such as an accidental spill on a river stretch.

A shear infinity of causes of mistakes is possible in the starting with sample collection, transport, storage and analysis up to entering into files and computers. Since it is best to detect mistakes as soon as possible after they have been made, extensive data checking is done upon entering data in the laboratories.

Part of these checks will be described in the following, such as Rosner's test for detecting one or more outliers in a series of observations. After identification of one or more outliers, a decision has to be made what to do with the data point. If an obvious mistake is detected than, if possible, the corrected value will be entered. Otherwise the data point may be excluded.

5.9.3.2 Control charts

Control charts should be established for all monitoring stations and all parameters based upon historical data. These plots serve as a guide for when investigation action is required. The control chart is usually made based on individual data points. Values for the previous 3 years are used to calculate the mean and upper/lower limits. New values can then be compared to the historical range of data. If there are a lot (many years) of data, annual or seasonal means can be used instead of individual data points. In this case, it will be better to use the previous 5-10 years of data to make the control chart, in order to have enough data values.

5.9.3.3 Outliers

Data outliers are extreme (high or low) values that do not conform with the main body of a data set. Outliers in water quality data sets can occur due to practical mistakes or instrumental failure in all aspects of water quality sampling and analysis: from sample collection, transport, storage, analysis or data entry. They may result from transcription or keypunch errors, or can be the result of instrument breakdowns, calibration problems or power failures. The presence of one or more outliers within a data set may greatly influence any calculated statistics and yield biased results. Thus outliers should be identified, flagged, and possibly removed from a data set. Several procedures have been developed as alternative methods for detecting outliers, including statistical tests to determine whether an observation appears extreme and does not fit the distribution of the rest of the data.

5.10 REPORTING

With the larger amount of digital data to be stored in the WInKS this is now, neither practical nor desirable as legitimate users can easily be provided with the precise data they need in the format they require.

What is now required is a readily available document indicating what information is available and held in the WInKS. This should include the following:

- maps showing observation stations within their catchment and administrative contexts
- lists showing the stations and the period of record available
- summary description of salient facts associated with stations
- summary hydrological information for all stations, e.g. annual and monthly totals
- significant trends in the behavior of the hydrological variables or alarming situations which need immediate attention of planners and designers
- selective listings or graphs(e.g. daily values) to give examples of available formats.

Periodic publication of special reports showing long term statistics of stations or special reports on unusual events may also be prepared.

Otherwise specific data can be provided to users on the basis of need. A wide range of tabular and graphical formats will be available, for example showing comparisons of current year values with long-term statistics, thematic maps of variables such as annual and seasonal rainfall, duration and frequency curves, etc. More detailed information such as stage discharge ratings can be provided to meet specific needs.

6. Data Management

This part of the project has been included in a specific detailed document which constitutes the Terms of Reference for the implementation of the WINKS, the Water Information and Knowledge management System), covering surface water and groundwater quantity and quality data for regional bureaus to the central department in Addis Ababa.

The WInKS (*Water Information and Knowledge management System)* comprises the physical infrastructure and human resources training required to process, validate, store and disseminate these data. The physical infrastructure includes data entry, processing and storage centers. Efficiency requires that all activities in the WInKS are well tuned to each other, whereas consistency and exchangeability of data demands the use of compatible tools and standardized techniques and procedures.

The WInKS will provide information on the spatial and temporal characteristics of water quantity and quality variables/parameters describing the water resources/water use system. This information should be tuned to the needs of decision/policy makers, designers and researchers to be able to take decisions, to design or to study the water resources system at large or its components. The establishment of a demand oriented and reliable WInKS requires upgrading and expansion of the physical infrastructure and adoption of standard tools, techniques and procedures. An important activity in the WInKS is to efficiently generate reliable information from the collected raw data. This is ensured by bringing the raw data on to the magnetic media and subsequently employing quality checks, carrying out necessary processing activities and finally reporting the information in a most suitable manner.

Figure 69 Role of WInKS

As such, it is envisaged to have several Data Entry Centers at the lowest level of the system which corresponds to the Regional Offices of the Hydrology Department in the MoWR (here-in-after referred to as Regional Offices) and the Hydrology Department in the MoWR in Addis Ababa (here-in-after referred to as Central Office).

The raw data collected by observers will be collected by the Regional Office, and automatic stations will be collected to the Central Office (to limit the computer investment). Finally, the fully processed data would be properly stored on dissemination server and archived by the Computer department of the MoWR (here-in-after referred to as Computer Office)

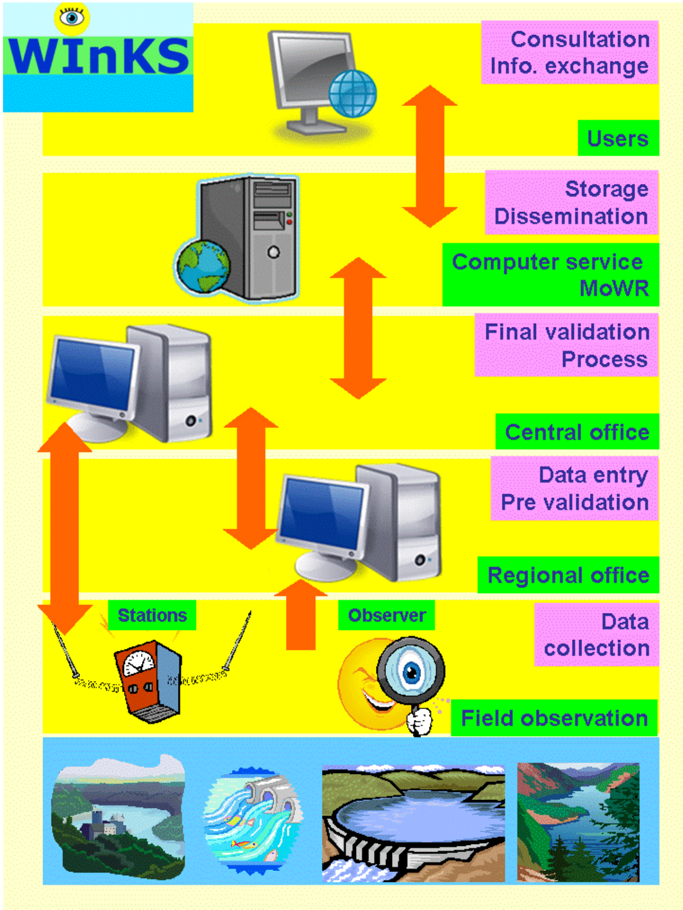


Figure 70 WInKS architecture

The WInKS Application Software is expected to facilitate data entry, processing, validation and dissemination of periodic reports, under a unique Web integrated software environment that comprises a database and application tools including GIS tools. The system needs to have a modular structure adjustable to the functions carried out at the different levels (Regional and Central Offices). As Web architecture will be implemented, a single but global software package will be adapted just, by user right assignments.

7. Capacity Building

7.1 GENERAL

At a superficial level, “capacity building” can be equated to training. However, it is well known that training may benefit individuals without strengthening the capacities of institutions.

Part of the WATER INFORMATION AND KNOWLEDGE MANAGEMENT PROJECT, staff will benefit from training, but capacity building will also include building institutional capacities, by knowledge and processes.

7.2 RECOMMENDATIONS

7.2.1 Institutional capacity building for project sustainability

After implementation phase, the WInKS project will entering in the crucial stage of its life “after”, and will be concerned by sustainability. Among various factors that have been identified as crucial to sustainability, organization culture is the one that stands out in significance.

7.2.1.1 End user utilization

The need to ensure cultural compatibility of the end users (such other water stakeholders), or staff in Central and Regional Offices, to the technology and processes introduced through the project, thus, assumes a critical importance.

Workshops

To assess the cultural environment of the agencies’ organizations, and to ensure that the culture of these organizations is supportive of the project, institutional development interventions must be done by holding workshops.

WInkS Data users group

To ensure that the WInKS output responds to the needs of the users, some WInkS Data users group must be constituted for representing current and potential users of data. By creating this group, it permits:

- To provide a common platform for discussions between hydrology data users and data providers.
- To create awareness amongst users about WInKS data and educate them on the potentials and limitations of WInKS.
- To understand, analyze and update information on the changing needs of data users from a macro level perspective.
- To review and recommend additions/deletions in the data collection networks and associated functions, if appropriate

7.2.1.2 WInKS sustainability

- Based on experience of other projects, critical factors for sustainability of WInKS will be:
- Availability of adequate ‘technical’ and ‘specialist ‘ experienced staff

- Stability in staff postings for functions
- Continuous training for up-gradating of skills
- Proper maintenance of instruments and machines
- Adequate budget provisions for O&M functions
- Regular and timely flow of funds
- Motivated staff
- Reduction of data quality

Concerning the last item, reduction of data quality can be avoided by:

- Improving telecommunication network (between regional and central offices)
- Timely up-gradation of software
- stand-by equipment and spares
- Making accessibility of sites during all seasons
- Availability of vehicles for effective operation supervision
- Simultaneous development of organisational capability for sustaining the level of technology
- Refresher courses for data collection staff
- Motivational workshops for quality consciousness

7.2.2 Training plan

The staff required to carry out different activities under WInKS are to be made available and very importantly. They must all be trained to carry out the desired tasks. Such training support is to be ensured on a sustainable basis since there will always be a need for training more staff, to replace staff moving out due to retirements and rotational transfers.

An in-house capacity building by a strong training component would also go a long way in bridging the remaining gaps. Training courses must be done on:

N°	Course purpose	Staff
	Data collection procedures	
A-1	General knowledge on hydrometry	Gauge readers/observers
A-2	Sensor operation and maintenance	Hydrologist and hydrogeologist staff
A-3	General knowledge on DCP (Groundwater and Surface Water); - operation and maintenance	Hydrologist and hydrogeologist staff
A-4	In-depth knowledge on DCP (Groundwater and Surface Water); - operation and maintenance	Hydrologist and hydrogeologist staff
A-5	Sediment equipments – sampling and maintenance	Hydrologist and hydrogeologist staff
A-6	Water quality sampling and field parameters acquisition	Hydrologist and hydrogeologist staff
A-7	General knowledge on Water Quality analytical procedures	Hydrologist and hydrogeologist staff

N°	Course purpose	Staff
	Project implentation	
IS1	General Knowledge of Sensors	All staff
IS2	Sensor Maintenance	Computer, Hydrologist and hydrogeologist staff
IS3	Measurement Interpretation	Computer, Hydrologist and hydrogeologist staff
AS1	Basic Knowledge of DCP and logger	Computer, Hydrologist and hydrogeologist staff
AS2	In-depth Knowledge of DCP and logger	Computer, Hydrologist and hydrogeologist staff
AS3	Operator Management of Man/machine Interface	All staff
AS4	Man/machine Interface configuration	Computer staff
AS5	Telecommunication Equipment	Computer staff
AS6	SCADA System General Architecture	All staff
CS1	Computer System General Architecture	Computer, Hydrologist and hydrogeologist staff
CS2	System Management: Engineer Level	Computer, Hydrologist and hydrogeologist staff
CS3	System Management: Operator Level	All Staff
CS4	Supervision System Configuration	Computer, Hydrologist and hydrogeologist staff
CS5	System Maintenance	Computer staff
CS6	Database Management Software	Compute staff
CS7	Hydrological and hydrogeological database	Hydrologist and hydrogeologist staff
CS8	SCADA System Presentation	Manager

7.2.3 Technical assistance for WInKS

A Technical Assistance will be helpful after commissioning, for WInKS start-up in operational running step. A Hydrometric engineer can assist the MoWR during 12 months in:

- Evaluating the WInKS performances (equipments and staff)
- Defining operating procedures and manuals to improve the performances
- Training the staff for technical operations
- Assisting in WInKS operation and maintenance

8. Financial estimation

8.1 INVESTMENTS

8.1.1 Control centre

	Quantity	Unit price (US$)	sub-total (US$)
General :Studies - Documentation - Training			
Design- Documentation			
Detailed design of the overall system	1	37 500,00	37 500,00
Detail design of Control Centre	1	15 000,00	15 000,00
Tests and acceptance test for the overall system	1	60 000,00	60 000,00
Documentation for the overall system	1	22 500,00	22 500,00
			135 000,00
Training			
General Knowledge of Sensors	1	7 350,00	7 350,00
Sensor Maintenance	1	11 025,00	11 025,00
Measurement Interpretation	1	16 800,00	16 800,00
Basic Knowledge of DCP and logger	1	18 375,00	18 375,00
In-depth Knowledge of DCP and logger	1	18 375,00	18 375,00
Operator Management of Man/machine Interface	1	21 000,00	21 000,00
Man/machine Interface configuration	1	29 400,00	29 400,00
Telecommunication Equipment	1	27 720,00	27 720,00
SCADA System General Architecture	1	21 000,00	21 000,00
System Management: Engineer Level	1	21 000,00	21 000,00
System Management: Operator Level	1	55 125,00	55 125,00
Supervision System Configuration	1	17 325,00	17 325,00
System Maintenance	1	17 325,00	17 325,00
Database Management Software	1	17 325,00	17 325,00
Hydrological and hydrogeological database	1	18 375,00	18 375,00
SCADA System Presentation	1	36 120,00	36 120,00
			353 640,00

	Quantity	Unit price (US$)	sub-total (US$)
Control Center			
Acquisition			
Satellite terminal for DCP links	2	1 200,00	2 400,00
Satellite communications costs (for 2 year)	2	500,00	1 000,00
Redundancy management	1	18 000,00	18 000,00
Front end computer	2	2 700,00	5 400,00
Front end software	2	16 500,00	33 000,00
Front end set-up	1	7 500,00	7 500,00
Supervisory			
Supervisory server	1	6 300,00	6 300,00
Web Supervisory software	1	31 500,00	31 500,00
Web supervisory set-up	1	13 500,00	13 500,00
Hydrological & hydrogeological database			
Web GIS interface software	1	28 500,00	28 500,00
Web hydrological database software	1	34 500,00	34 500,00
Web hydrogeological database software	1	25 500,00	25 500,00
Dedicated development for ENGDA functions implementation	1	22 500,00	22 500,00
Dedicated development for HYDATA functions implementation	1	10 500,00	10 500,00
Web database setup	1	18 000,00	18 000,00
Other			
Workstations	5	3 150,00	15 750,00
LAN equipements	1	1 500,00	1 500,00
WAN equipements (VSAT ?)	1	4 050,00	4 050,00
VSAT communications costs (for 2 year)	2	5 040,00	10 080,00
Civil works (Layout for main control center)	1	22 500,00	22 500,00
UPS	1	3 750,00	3 750,00
Printers	1	1 800,00	1 800,00
Maintenance laptop	3	1 500,00	4 500,00
Protocol analyser	1	1 200,00	1 200,00
Consumables	1	1 500,00	1 500,00
			324 730,00

	Quantity	Unit price (US$)	sub-total (US$)
Regional offices (9)			
Workstations	18	3 150,00	56 700,00
LAN equipements	9	450,00	4 050,00
WAN equipements (VSAT ?)	9	2 550,00	22 950,00
VSAT communications costs (for 2 year)	18	2 880,00	51 840,00
Civil works (Layout for regional control room)	9	1 800,00	16 200,00
UPS	9	1 200,00	10 800,00
Printers	9	750,00	6 750,00
Consumables	9	300,00	2 700,00
			171 990,00
Control Centre : total			
		Subtotal	985 360,00
		Provisions 10%	98536
		Total per site (without any taxes)	1 083 896,00

8.1.2 Groundwater site

Groundwater water level	Quantity	Unit price	sub-total
General : Studies - Documentation - Training			
Design- Documentation			
Detail design of groundwater site	1	600,00	600,00
Tests and acceptance test for the groundwater site	1	150,00	150,00
Documentation for the groundwater site	1	150,00	150,00
Equipment			
Acquisition			
Furniture of a Data logger with sensor	1	4 050,00	4 050,00
Installation of a Data logger	1	450,00	450,00
Data logger setup	2	150,00	300,00
Control center			
Front end computer - Supervisory - Hydrogeological database set-up for this specific datalogger	1	450,00	450,00
Maintenance			
Part of the spart part	1	810,00	810,00
Ground water water level : total			
		Subtotal	6 960,00
		Provisions 10%	696
		Total per site (without any taxes)	7 656,00

8.1.3 Surface water site

Surface water level	Quantity	Unit price	sub-total
General : Studies - Documentation - Training			
Design- Documentation			
Detail design of surfacewater site	1	1 200,00	1 200,00
Tests and acceptance test for the surfacewater site	1	450,00	450,00
Documentation for the surfacewater site	1	225,00	225,00
Equipment			
Acquisition			
Furniture of a Data Collection Plateform	1	8 250,00	8 250,00
Furniture of a radar sensor with its mast	1	3 300,00	3 300,00
Furniture of the satellite terminal	1	1 200,00	1 200,00
Satellite communications costs (for 2 year)	2	500,00	1 000,00
Installation of equipments	1	2 100,00	2 100,00
DCP and all eaquipments setup	2	600,00	1 200,00
Control center			
Front end computer - Supervisory - Hydrogeological database set-up for this specific DCP	1	900,00	900,00
Maintenance			
Part of the spart part	1	2 550,00	2 550,00
Surface water level : total			
		Subtotal	22 375,00
		Provisions 10%	2237,5
		Total per site (without any taxes)	24 612,50

8.1.4 Options

Options	Quantity	Unit price (US$)	sub-total (US$)
Technical assistance (6 months per year during 2 years)	1	231 000,00	231 000,00
Maintenance (per year for the control center)	1	56 854,80	56 854,80
Maintenance (per year for a ground water logger)	1	367,50	367,50
Maintenance (per year for a surface water logger)	1	1 186,50	1 186,50

8.2 INVESTMENT SIMULATION

Financial simulation for 30 groundwater sites, 80 surface water sites, the control centre.

Investment simulation	Quantity	Unit price (US$)	sub-total (US$)
Control center	1	1 083 896,00	1 083 896,00
Ground water site	30	7 656,00	229 680,00
Surface water site	80	24 612,50	1 969 000,00
Technical assistance (6 months per year during 2 years)	1	231 000,00	231 000,00
Maintenance during 2 years	2	162 799,80	325 599,60
		Total per site (without any taxes)	3 839 175,60

8.3 OPERATION COSTS SIMULATION

Financial simulation for 30 groundwater sites, 80 surface water sites, the control centre.

Operation simulation	Quantity	Unit price (US$)	sub-total (US$)
Maintenance during 1 year	1	162 799,00	162 799,00
Telecommunications	1	71 460,00	71 460,00
		Total per site (without any taxes)	234 259,00

ANNEX

Annex 1: List of envisaged water level station locations

WATER LEVEL STATIONS						
ABBAY	Lake	LK001	Kunzila	Lake Tana	282 161,15	1 316 280,10
ABBAY	Lake	LK002	Bahr Dar	Lake Tana	323 370,76	1 282 825,24
ABBAY	Lake	LK003	Gorgora	Lake Tana	315 073,06	1 352 568,08
ABBAY	Lake	LK004	Shambu		300 531,74	1 049 563,75
ABBAY	Main station	MS001	Weberi	Robi Jida	500 000,00	1 064 504,44
ABBAY	Main station	MS002	Weberi	Robigumer	500 000,00	1 077 771,82
ABBAY	Main station	MS003	Fetire	Jemma	489 037,77	1 096 569,08
ABBAY	Main station	MS004	Fetire	Wenchit	475 894,85	1 114 265,69
ABBAY	Main station	MS005	Ejere		443 038,20	1 111 392,35
ABBAY	Main station	MS006	Gende Bune		529 427,25	1 126 746,91
ABBAY	Main station	MS007	Jihur		535 075,56	1 111 847,07
ABBAY	Main station	MS008	Dejen-Goha Tsion	Abbay	411 096,25	1 113 950,43
ABBAY	Main station	MS009	Bete Nigus		384 816,97	1 095 069,63
ABBAY	Main station	MS010	Jemo Lefo		404 833,31	1 062 980,25
ABBAY	Main station	MS011	Minare		407 374,66	1 066 693,13
ABBAY	Main station	MS012	Muger		453 826,72	1 049 030,50

WATER LEVEL STATIONS						
ABBAY	Main station	MS013	Kewo		352 554,69	1 088 600,63
ABBAY	Main station	MS014	Kombolcha		351 977,22	1 042 153,19
ABBAY	Main station	MS015	Guder	Debis	364 803,29	997 290,86
ABBAY	Main station	MS016	Asendabo	Fincha	319 743,19	1 106 337,13
ABBAY	Main station	MS017	Fincha-a	Fincha	316 704,03	1 058 115,91
ABBAY	Main station	MS018	Ageyo	Didessa	221 128,79	888 474,91
ABBAY	Main station	MS019	Arjo	Didessa	216 084,89	960 439,36
ABBAY	Main station	MS020	Wama Adere	Sifa	255 845,87	981 209,40
ABBAY	Main station	MS021	Koye		246 094,19	944 349,29
ABBAY	Main station	MS022	Jogir	Dabana	175 643,30	999 480,33
ABBAY	Main station	MS023	Arjo	Didessa	187 479,53	999 812,26
ABBAY	Main station	MS024	Tsige Maryam	Uke	218 296,85	1 042 877,90
ABBAY	Main station	MS025	Golo	Little An	234 308,25	1 051 058,04
ABBAY	Main station	MS026	Golo	Angar	227 661,81	1 043 358,47
ABBAY	Main station	MS027	Golo	Uke	227 575,93	1 031 186,06
ABBAY	Main station	MS028	Haro		176 503,81	1 058 893,75

WATER LEVEL STATIONS						
ABBAY	Main station	MS029	Hena		172 600,60	1 058 207,24
ABBAY	Main station	MS030	Babo		258 131,20	907 774,00
ABBAY	Main station	MS031	Debeka		84 789,63	1 029 491,88
ABBAY	Main station	MS032	Debeka		55 967,41	1 047 266,06
ABBAY	Main station	MS033	Debeka		56 045,98	1 052 871,33
ABBAY	Main station	MS034	Benguwa	Dabus	50 359,39	1 094 254,00
ABBAY	Main station	MS035	Daleti		61 722,25	1 126 412,75
ABBAY	Main station	MS036	Godere		77 854,91	1 172 826,63
ABBAY	Main station	MS037	Abatimbo El Gumas	Abbay	80 133,81	1 179 237,54
ABBAY	Main station	MS038	Abbay	Abbay	126 922,46	1 113 511,98
ABBAY	Main station	MS039	Daleti		113 777,27	1 122 762,70
ABBAY	Main station	MS040	Debre Zeit	Abay	86 973,48	1 210 284,91
ABBAY	Main station	MS041	Mankush		154 928,41	1 229 681,00
ABBAY	Main station	MS042	Mankush		126 262,22	1 232 354,63
ABBAY	Main station	MS043	Pawe		207 452,13	1 238 191,88
ABBAY	Main station	MS044	Yismala		257 917,50	1 291 608,63

WATER LEVEL STATIONS						
ABBAY	Main station	MS045	Surge		139 181,41	1 103 097,63
ABBAY	Main station	MS046	Korka		200 714,03	1 126 456,25
ABBAY	Main station	MS047	Kilaj		216 723,67	1 157 764,88
ABBAY	Main station	MS048	Gomer		244 761,91	1 141 313,00
ABBAY	Main station	MS049	Gomer		255 192,19	1 150 604,38
ABBAY	Main station	MS050	Kuch	Abbay	283 008,05	1 138 350,52
ABBAY	Main station	MS051	Kuch		289 625,72	1 139 699,63
ABBAY	Main station	MS052	Inewend		303 216,25	1 141 847,38
ABBAY	Main station	MS053	Kuch	L. Fettam	282 902,44	1 159 395,00
ABBAY	Main station	MS054	Jiga	Birr	322 797,33	1 177 743,28
ABBAY	Main station	MS055	Kewo		334 510,72	1 109 364,72
ABBAY	Main station	MS056	Ajibar		448 037,75	1 200 387,97
ABBAY	Main station	MS057	Shil Afaf		509 501,70	1 149 032,46
ABBAY	Main station	MS058	Gundo Meskel		470 224,70	1 148 715,71
ABBAY	Main station	MS059	Wegeda		444 102,34	1 227 521,32
ABBAY	Main station	MS060	Bete Hor		467 867,70	1 265 764,44

WATER LEVEL STATIONS

ABBAY	Main station	MS061	Bete Hor		470 872,52	1 261 940,13
ABBAY	Main station	MS062	Kon		503 106,01	1 275 871,55
ABBAY	Main station	MS063	Wegel Tena		527 932,04	1 269 356,53
ABBAY	Main station	MS064	Zege	Gilgel Abay	295 725,40	1 303 692,23
ABBAY	Main station	MS065	Wetet Abay	Gelgel A.	285 023,16	1 257 619,82
ABBAY	Main station	MS066	Bahr Dar	Abbay	325 551,89	1 282 812,91
ABBAY	Main station	MS067	Wanzaye	Gumara	350 757,13	1 308 121,33
ABBAY	Main station	MS068	Robit	Megech	322 395,16	1 356 258,44
ABBAY	Main station	MS069	Woreta	Ribb	360 649,70	1 326 877,30
ABBAY	Main station	MS070	Ibnat	Upper Rib	388 978,85	1 332 288,87
ABBAY	Main station	MS071	Mota		379 033,89	1 239 959,58
ABBAY	Main station	MS072	Mankush		127 692,99	1 288 273,38
ABBAY	Main station	MS073	Tewodros Ketema		148 396,03	1 309 128,13
ABBAY	Main station	MS074	Tewodros Ketema		162 719,53	1 329 429,13
ABBAY	Main station	MS075	Tewodros Ketema		161 981,94	1 352 960,13
ABBAY	Main station	MS076	Mahbere Silase		197 707,84	1 392 852,25

WATER LEVEL STATIONS						
ABBAY	Main station	MS077	Mahbere Silase		212 095,69	1 375 540,00
ABBAY	Main station	MS078	Tewodros Ketema		195 081,50	1 328 446,00
ABBAY	Secondary station	SE003	Wetet Abay	Koga	287 206,45	1 257 605,09
ABBAY	Secondary station	SE007	Azezo	Megech	331 554,08	1 380 124,47
ABBAY	Secondary station	SE009	Gonder	Angareb	334 910,74	1 396 698,29
ABBAY	Secondary station	SE011	Gasay	Zufil	399 783,35	1 307 920,44
ABBAY	Secondary station	SE012	Anbesame	Gelda	350 687,02	1 293 742,62
ABBAY	Secondary station	SE013	Gasay	Ribb	407 398,99	1 304 578,66
ABBAY	Secondary station	SE014	Meksenyit	Gemero	342 363,48	1 369 001,58
ABBAY	Secondary station	SE015	Arb Gebeya	Fegoda	365 913,96	1 285 930,47
ABBAY	Secondary station	SE016	Meksenyit	Garno	349 889,72	1 352 369,80
ABBAY	Secondary station	SE017	Bahr Dar	Ezana	325 477,72	1 269 539,18
ABBAY	Secondary station	SE018	Merawi	Bered	300 340,63	1 263 051,16
ABBAY	Secondary station	SE019	Dangla	Amen	267 475,15	1 246 678,70
ABBAY	Secondary station	SE020	Filikilik	Abbay	412 648,19	1 115 562,83
ABBAY	Secondary station	SE021	Chancho	Mugher	470 347,97	1 028 030,90

WATER LEVEL STATIONS						
ABBAY	Secondary station	SE023	Tis Abay	Andassa	334 217,47	1 271 704,08
ABBAY	Secondary station	SE024	Debre Birhan	Beressa	557 046,97	1 068 970,37
ABBAY	Secondary station	SE025	Mehal Meda	Wizer	574 473,59	1 130 920,77
ABBAY	Secondary station	SE026	Chacha	Chacha	551 582,74	1 053 483,39
ABBAY	Secondary station	SE027	Mehal Meda	Shy	562 422,07	1 133 108,83
ABBAY	Secondary station	SE028	Mulo	Aleltu	464 861,81	1 033 563,52
ABBAY	Secondary station	SE029	Chancho	Deneba	469 247,13	1 024 714,95
ABBAY	Secondary station	SE030	Chancho	Sibilu	472 539,00	1 020 290,11
ABBAY	Secondary station	SE031	Chancho	Roba	474 737,31	1 022 499,82
ABBAY	Secondary station	SE032	Adet	Shina	336 256,47	1 244 040,51
ABBAY	Secondary station	SE033	Dejen	Muga	406 889,42	1 124 330,34
ABBAY	Secondary station	SE034	Keraniya	Azuari	392 925,35	1 212 836,59
ABBAY	Secondary station	SE035	Achewa Bado	Tigdar	392 893,08	1 202 883,94
ABBAY	Secondary station	SE036	Dogolo	Gebregura	527 363,04	1 151 860,56
ABBAY	Secondary station	SE037	Kabe	Selgi	545 921,03	1 188 368,44
ABBAY	Secondary station	SE038	Kurkura	Mechela	538 269,94	1 186 147,43

WATER LEVEL STATIONS						
ABBAY	Secondary station	SE039	Were Ilu	Jogola	547 040,51	1 169 572,88
ABBAY	Secondary station	SE040	Weberi	Aleltu	494 514,46	1 066 716,06
ABBAY	Secondary station	SE043	Webrje	Teme	388 353,57	1 152 029,52
ABBAY	Secondary station	SE044	Bichena	Suha	410 246,60	1 151 965,93
ABBAY	Secondary station	SE045	Mekane Selam	Boreda	475 946,27	1 188 345,66
ABBAY	Secondary station	SE046	Mekane Selam	Lege Cora	475 947,86	1 190 557,05
ABBAY	Secondary station	SE048	Tis Abay	Mendel	344 024,49	1 269 441,56
ABBAY	Secondary station	SE049	Mota	Sedie	379 837,05	1 219 517,26
ABBAY	Secondary station	SE050	Chemoga	Yeda	370 768,76	1 133 290,40
ABBAY	Secondary station	SE051	Mekane Eyesus	Chena	394 256,42	1 284 714,85
ABBAY	Secondary station	SE052	Mekane Eyesus	Wenka	398 617,34	1 284 700,28
ABBAY	Secondary station	SE053	Guder	Bello	353 749,99	980 741,56
ABBAY	Secondary station	SE054	Guder	Fatto	359 249,00	980 722,24
ABBAY	Secondary station	SE055	Guder	Guder	362 578,26	989 557,56
ABBAY	Secondary station	SE056	Chemoga	Chemoga	360 932,54	1 138 857,46
ABBAY	Secondary station	SE057	Yewla	Jedeb	343 458,59	1 149 991,14

WATER LEVEL STATIONS						
ABBAY	Secondary station	SE058	Dembecha	Gudla	335 873,10	1 166 616,88
ABBAY	Secondary station	SE060	Dembecha	Temcha	335 862,50	1 164 404,82
ABBAY	Secondary station	SE061	Jiga	Leza	317 338,61	1 179 984,55
ABBAY	Secondary station	SE062	Finote Selam	Lah	310 780,28	1 181 126,78
ABBAY	Secondary station	SE063	Tilili	Fettam	283 548,26	1 200 098,17
ABBAY	Secondary station	SE064	Chagni	Dura	224 604,06	1 214 922,09
ABBAY	Secondary station	SE065	Achane	Neshi	308 034,75	1 078 268,40
ABBAY	Secondary station	SE066	Chagni	Dondor	228 932,45	1 209 352,37
ABBAY	Secondary station	SE067	Chagni	Ardy	228 950,65	1 211 565,71
ABBAY	Secondary station	SE068	Ambo	Huluka	376 871,96	989 511,56
ABBAY	Secondary station	SE069	Dangla	Quashini	267 419,02	1 238 933,67
ABBAY	Secondary station	SE070	Kidamaja	Buchiksi	248 693,13	1 219 155,41
ABBAY	Secondary station	SE073	Guder	Indris	362 570,76	987 345,92
ABBAY	Secondary station	SE074	Lumame	Bogena	385 007,70	1 133 241,09
ABBAY	Secondary station	SE075	Koso Ber	Missini	267 205,78	1 209 060,26
ABBAY	Secondary station	SE076	Chemoga	Abahim	360 932,54	1 138 857,46

WATER LEVEL STATIONS

ABBAY	Secondary station	SE080	Wama Adere	Wama	255 786,65	971 252,18
ABBAY	Secondary station	SE084	Yebu	Yebu	248 542,67	859 547,82
ABBAY	Secondary station	SE085	Gembe	Urgessa	243 061,99	866 216,19
ABBAY	Secondary station	SE086	Gute	Tato	241 654,11	999 000,78
ABBAY	Secondary station	SE087	Sire	Indris	263 651,33	998 865,13
ABBAY	Secondary station	SE088	Abdela	Dabana	200 449,17	929 558,18
ABBAY	Secondary station	SE092	Asosa	Hoha	20 850,10	1 125 221,86
ABBAY	Secondary station	SE093	Toba	Hujur	97 075,88	1 066 665,35
ABBAY	Secondary station	SE094	Asosa	Haffa	24 979,90	1 105 207,62
ABBAY	Secondary station	SE095	Toba	Sechi	85 068,73	1 074 552,38
ABBAY	Secondary station	SE096	Asosa	Gambella	19 528,78	1 108 606,17
ABBAY	Secondary station	SE097	Debeka	Aleltu	60 624,54	1 052 665,98
ABBAY	Secondary station	SE098	Nejo	Dilla	121 058,83	1 046 478,40
ABBAY	Secondary station	SE099	Jarso	Komis	102 502,18	1 059 960,52
ABBAY	Secondary station	SE100	Bambesi	Mutsa	31 261,98	1 080 733,85
ABBAY	Secondary station	SE102	Mandura	Gilgel Be	212 760,65	1 236 054,28

WATER LEVEL STATIONS						
ABBAY	Secondary station	SE103	Mandura	Main Bele	221 580,08	1 244 831,59
ABBAY	Secondary station	SE104	Gute	Adiya	236 183,52	1 003 462,60
ABBAY	Secondary station	SE105	Mankusa	Abbay	294 315,00	1 172 372,73
ABBAY	Secondary station	SE106	Bahr Dar	Abbay	327 733,01	1 282 800,74
ABBAY	Secondary station	SE107	Kidamaja	Ayo	257 397,49	1 213 557,04
ABBAY	Secondary station	SE109	Dembecha	Chereka	328 239,90	1 172 184,79
ABBAY	Secondary station	SE110	Kachisi	Tilku Dub	377 051,89	1 047 012,47
ABBAY	Secondary station	SE111	Dese	Gerado	565 525,23	1 227 102,57
ABBAY	Secondary station	SE112	Addis Abeba	Gerbi	463 743,26	1 011 452,43
ABBAY	Secondary station	SE113	Gorfo	Gorfo	481 335,57	1 039 080,07
ABBAY	Secondary station	SE116	Toba	Koriche	91 543,06	1 063 401,25
ABBAY	Secondary station	SE117	Guder	Melke	360 341,24	978 506,82
ABBAY	Secondary station	SE118	Komosh	Shelkole	18 012,28	1 158 528,43
ABBAY	Secondary station	SE119	Jiga	Talia	327 258,92	1 194 311,87
ABBAY	Secondary station	SE120	Chobi	Tinshu Du	377 044,78	1 044 800,87
ABBAY	Secondary station	SE121	Adet	Tul	334 032,79	1 236 309,16

WATER LEVEL STATIONS						
ABBAY	Secondary station	SE173	Dese	Kelina	563 340,98	1 227 098,24
ABBAY	Transboundary	TB010	Gizen		39 217,47	1 187 396,38
ABBAY	Transboundary	TB011	Omedila	Abbay	60 848,41	1 244 414,77
ABBAY	Transboundary	TB012	Omedila		92 989,22	1 322 594,17
ABBAY	Transboundary	TB013	Tewodros Ketema		129 829,43	1 386 383,63
ABBAY	Transboundary	TB014	Metema		150 162,31	1 402 603,13
AWASH	Lake	LK005	Adi Gala		820 970,77	1 202 526,90
AWASH	Lake	LK006	Adi Gala		801 031,84	1 235 058,84
AWASH	Lake	LK007	Deday		790 327,78	1 278 504,71
AWASH	Lake	LK008	Hayk	Lake Haik	574 206,15	1 251 448,80
AWASH	Lake	LK009	Gewane		663 977,94	1 130 746,76
AWASH	Lake	LK010	Metehara	Lake Besk	595 654,81	983 908,85
AWASH	Lake	LK011	Asbuli		737 723,63	1 205 307,52
AWASH	Lake	LK024	Koka	Lake Koka	509 177,70	927 042,22
AWASH	Main station	MS079	Hayu	Awash	767 214,39	1 277 938,72
AWASH	Main station	MS080	Dubti		747 528,41	1 283 309,39

WATER LEVEL STATIONS						
AWASH	Main station	MS081	Dubti	Awash	731 082,05	1 294 247,81
AWASH	Main station	MS082	Loqiya	Logia	715 792,80	1 297 456,10
AWASH	Main station	MS083	Tendaho	Awash	712 560,25	1 291 901,54
AWASH	Main station	MS084	Tendaho		672 778,00	1 314 559,25
AWASH	Main station	MS085	Weranso		655 214,06	1 277 053,00
AWASH	Main station	MS086	Mersa		608 159,50	1 285 589,88
AWASH	Main station	MS087	Jimate	Borkena	601 725,56	1 175 221,15
AWASH	Main station	MS088	Bati		635 344,25	1 207 030,88
AWASH	Main station	MS089	Gewane	Awash	673 694,88	1 131 378,25
AWASH	Main station	MS090	Debel		658 520,97	1 135 783,96
AWASH	Main station	MS091	Gewane		654 946,00	1 100 889,00
AWASH	Main station	MS092	Afdem		695 040,69	1 070 300,32
AWASH	Main station	MS093	Afdem		702 806,38	1 068 201,48
AWASH	Main station	MS094	Algeyta	Middle Awash	643 387,20	1 053 711,52
AWASH	Main station	MS095	Melka Werer	Awash	628 492,88	1 030 443,28
AWASH	Main station	MS096	Melka Sede	Awash	623 042,79	1 017 156,03

WATER LEVEL STATIONS

AWASH	Main station	MS097	Melka Sede	Kessem	604 379,49	1 011 573,44
AWASH	Main station	MS098	Awash	Awash	629 714,40	992 849,55
AWASH	Main station	MS099	Metehara	Awash	593 468,35	978 375,33
AWASH	Main station	MS100	Adis Hiywet	Awash	563 831,31	942 938,86
AWASH	Main station	MS101	Wenji	Awash	525 645,56	934 054,07
AWASH	Main station	MS102	Wenji	Awash	518 618,02	936 730,69
AWASH	Main station	MS103	Sire	Keleta	544 049,42	915 274,64
AWASH	Main station	MS104	Ombole	Awash	475 779,10	926 314,61
AWASH	Main station	MS105	Koka	Mojo	502 201,61	931 835,58
AWASH	Main station	MS106	Koka	Awash	502 201,78	928 518,96
AWASH	Main station	MS107	Melka Kunture	Awash	455 998,44	961 708,51
AWASH	Main station	MS108	Boneya	Akaki	469 203,13	967 224,51
AWASH	Main station	MS109	Akaki Beseka	Akaki	475 810,95	981 592,52
AWASH	Main station	MS110	Tefki	Awash	436 222,80	978 318,33
AWASH	Main station	MS111	Holota	Holeta	447 252,34	1 003 731,64
AWASH	Main station	MS112	Harawa		826 366,44	1 099 127,50

WATER LEVEL STATIONS						
AWASH	Main station	MS113	Adigala		842 061,94	1 124 965,50
AWASH	Main station	MS114	Asbuli		733 647,25	1 152 825,63
AWASH	Main station	MS115	Mile	Awash	694 397,47	1 230 936,70
AWASH	Main station	MS116	Mojo	Mojo	508 802,57	950 630,68
AWASH	Secondary station	SE125	Adis Alem	Bergaa	428 558,37	997 126,86
AWASH	Secondary station	SE127	Debre Genet	Teji	426 312,06	970 595,50
AWASH	Secondary station	SE129	Debre Zeyt	L.Bisheft	497 800,11	965 002,00
AWASH	Secondary station	SE136	Wenji	Hot Sprin	522 015,04	934 052,24
AWASH	Secondary station	SE137	Sendafa	Kessem	507 690,36	1 013 647,74
AWASH	Secondary station	SE139	Addis Abeba	Lit. Akak	467 028,38	998 182,44
AWASH	Secondary station	SE140	Debre Zeyt	Hora	497 800,35	969 424,23
AWASH	Secondary station	SE141	Debre Zeyt	Kuriftu	496 700,52	969 424,31
AWASH	Secondary station	SE142	Debre Zeyt	Bisho (Gu	497 800,11	965 002,00
AWASH	Secondary station	SE143	Sendafa	Mutincha	491 208,09	1 000 381,01
AWASH	Secondary station	SE145	Abomsa	Arba	590 236,34	947 409,35
AWASH	Secondary station	SE149	Awash	Arba	648 388,87	997 337,44

WATER LEVEL STATIONS						
AWASH	Secondary station	SE153	Hayk	Mille	568 735,25	1 258 071,31
AWASH	Secondary station	SE155	Hayk	Kete	574 211,30	1 249 237,20
AWASH	Secondary station	SE156	Kombolcha	Borkena	579 736,55	1 221 605,33
AWASH	Secondary station	SE157	Dese	Desso	568 794,58	1 230 426,67
AWASH	Secondary station	SE158	Shewa Robit	Robit	596 447,63	1 105 541,11
AWASH	Secondary station	SE159	Jewha	Jeweha	606 279,78	1 116 626,66
AWASH	Secondary station	SE160	Efeson	Ataye	606 203,41	1 142 060,04
AWASH	Secondary station	SE161	Jimate	Jara	603 950,41	1 163 063,79
AWASH	Secondary station	SE163	Kombolcha	Borkena	581 915,67	1 223 822,33
AWASH	Secondary station	SE164	Deday	Mille	802 278,24	1 263 867,28
AWASH	Secondary station	SE168	Hayu	Awash	767 233,34	1 275 725,36
AWASH	Secondary station	SE172	Boru	Borkena	567 681,69	1 240 376,37
AWASH	Secondary station	SE174	Mersa	Mersa	570 842,18	1 291 250,42
AWASH	Secondary station	SE175	Senbete	Senbete	606 213,47	1 138 742,62
AWASH	Secondary station	SE176	Asbe Teferi	Burka	705 528,71	1 004 226,22
AWASH	Secondary station	SE177	Erer	Erer 1St	765 668,56	1 054 377,67

WATER LEVEL STATIONS						
AWASH	Secondary station	SE178	Mieso	Mieso	694 452,85	1 020 762,37
AWASH	Secondary station	SE179	Kobo	Medessa	763 586,00	1 037 764,50
AWASH	Secondary station	SE180	Mieso	Mulo	699 919,35	1 026 320,60
AWASH	Secondary station	SE181	Mieso	Korangoga	706 529,85	1 023 036,47
AWASH	Secondary station	SE182	Gota	Erer 2Nd.	755 790,49	1 053 203,31
AWASH	Secondary station	SE183	Chelenko	Germam	776 637,06	1 056 669,37
AWASH	Secondary station	SE188	Ginchi	Awash	404 376,57	997 177,15
AWASH	Secondary station	SE190	Ginchi	Jemjem	404 371,31	994 965,76
AWASH	Secondary station	SE191	Addis Abeba	Kebena	475 820,20	997 070,60
AWASH	Secondary station	SE192	Adis Alem	Kela	419 760,71	994 932,14
AWASH	Secondary station	SE195	Awash	Kurkura	637 395,36	997 298,32
AWASH	Secondary station	SE196	Mersa	Megenagna	570 862,43	1 282 403,87
BARO AKOBO	Main station	MS117	Wanke		-39 126,13	944 301,31
BARO AKOBO	Main station	MS118	Itang	Baro	-21 583,55	907 265,74
BARO AKOBO	Main station	MS119	Punydo	Gilo	-22 289,96	845 152,26
BARO AKOBO	Main station	MS120	Abobo	Alwero	3 929,95	872 508,83

WATER LEVEL STATIONS						
BARO AKOBO	Main station	MS121	Gambela	Baro	11 625,12	912 431,54
BARO AKOBO	Main station	MS122	Bure		58 098,71	921 462,47
BARO AKOBO	Main station	MS123	Masha	Upper Bar	110 635,88	871 570,10
BARO AKOBO	Main station	MS124	Toom	U. Akobo	85 092,78	720 014,88
BARO AKOBO	Main station	MS125	Tepi		103 522,86	789 352,40
BARO AKOBO	Main station	MS126	Metu		125 408,62	921 284,31
BARO AKOBO	Main station	MS127	Supe	Geba	131 074,93	938 955,02
BARO AKOBO	Main station	MS128	Yubdo	Birbir	112 816,39	991 176,36
BARO AKOBO	Main station	MS129	Chanka	Keto	61 931,22	971 746,79
BARO AKOBO	Main station	MS130	Tepi		51 384,55	806 336,38
BARO AKOBO	Main station	MS131	Kelo		103 015,35	969 697,89
BARO AKOBO	Main station	MS132	Bure		80 546,13	949 487,79
BARO AKOBO	Main station	MS133	Kumbabe		173 547,56	926 421,88
BARO AKOBO	Main station	MS269	Bonga	Baro	44 721,01	908 751,68
BARO AKOBO	Secondary station	SE197	Metu	Sore	125 408,62	921 284,31
BARO AKOBO	Secondary station	SE202	Uka	Uka	97 678,38	904 914,67

WATER LEVEL STATIONS						
BARO AKOBO	Secondary station	SE203	Gore	Gumero	112 006,06	902 571,84
BARO AKOBO	Secondary station	SE204	Dembidolo	Meti	40 716,00	947 590,15
BARO AKOBO	Secondary station	SE205	Guliso	Ouwa	118 533,93	1 013 274,40
BARO AKOBO	Secondary station	SE207	Tepi	Begwuha	105 593,90	795 184,58
BARO AKOBO	Secondary station	SE208	Tepi	Bitinwuha	105 593,90	795 184,58
BARO AKOBO	Secondary station	SE209	Tepi	Beko(Shoh	107 823,42	797 382,47
BARO AKOBO	Secondary station	SE210	Chanka	Kuni	68 638,28	980 541,54
BARO AKOBO	Secondary station	SE211	Alem Teferi	Merdefa	78 533,53	978 222,31
BARO AKOBO	Secondary station	SE215	Temenja Yazhi	Gacheb	118 735,12	777 363,96
BARO AKOBO	Secondary station	SE216	Chanka	Cherecha	74 125,40	978 267,85
BARO AKOBO	Secondary station	SE218	Gecha	Gengi	105 921,65	836 164,87
BARO AKOBO	Secondary station	SE219	Dembidolo	Agami	42 744,73	930 941,19
BARO AKOBO	Secondary station	SE220	Mizan Teferi	Berhan	99 805,58	761 999,27
BARO AKOBO	Secondary station	SE221	Bonga	Bonga	42 478,20	905 449,48
BARO AKOBO	Secondary station	SE222	Supe	Eilika	131 122,86	944 491,85
BARO AKOBO	Transboundary	TB005	Jikawo		-74 370,71	928 153,19

WATER LEVEL STATIONS						
BARO AKOBO	Transboundary	TB015	Tirgol		-139 472,59	905 269,63
BARO AKOBO	Transboundary	TB016	Tirgol		-136 690,08	925 546,81
BARO AKOBO	Transboundary	TB017	Jikawo		-116 809,51	936 003,44
DENAKIL	Lake	LK022	Berahile		642 691,60	1 568 741,46
DENAKIL	Lake	LK023	Didigsala		706 366,80	1 468 122,63
DENAKIL	Main station	MS241	Weldiya	Alla Woha	574 052,96	1 315 586,49
DENAKIL	Main station	MS242	Zobl		625 692,19	1 347 178,25
DENAKIL	Main station	MS243	Weyra Wuha		613 078,50	1 380 646,50
DENAKIL	Main station	MS244	Didigsala		644 720,75	1 408 239,38
DENAKIL	Main station	MS245	Didigsala		626 731,06	1 416 537,50
DENAKIL	Main station	MS246	Didigsala		644 733,00	1 467 444,00
DENAKIL	Main station	MS247	Shehet		619 191,31	1 488 360,50
DENAKIL	Main station	MS248	Berahile		626 407,19	1 547 099,25
DENAKIL	Secondary station	SE224	Korem	Lake Ashe	556 485,72	1 389 640,20
DENAKIL	Secondary station	SE226	Robit	Golina	567 476,38	1 334 370,46
DENAKIL	Secondary station	SE227	Maychew	Babur	559 695,68	1 412 870,34

WATER LEVEL STATIONS

DENAKIL	Secondary station	SE228	Maychew	Meswait	557 542,92	1 404 018,74
DENAKIL	Secondary station	SE229	Korem	Gando	556 496,62	1 384 110,88
DENAKIL	Secondary station	SE230	Kobo	Hormat	565 285,08	1 341 000,68
GENALE DAWA	Main station	MS134	Dinshu	U. Weyb	583 083,68	781 502,23
GENALE DAWA	Main station	MS135	Robe	Shaya	607 103,24	792 655,01
GENALE DAWA	Main station	MS136	Gasera		624 029,89	804 687,20
GENALE DAWA	Main station	MS137	Goro	Weyib	678 961,57	771 845,45
GENALE DAWA	Main station	MS138	Goro	Weyib	702 201,72	763 082,27
GENALE DAWA	Main station	MS139	Ara Terra	Weyb	743 469,34	719 133,96
GENALE DAWA	Main station	MS140	El-Medo	Weyb	808 807,66	623 707,52
GENALE DAWA	Main station	MS141	Lema Shilindi	Weyb	846 581,90	534 855,20
GENALE DAWA	Main station	MS142	Bore		471 882,95	718 530,72
GENALE DAWA	Main station	MS143	Mejo		494 103,44	686 075,13
GENALE DAWA	Main station	MS144	Zembaba Wiha		536 889,72	660 869,70
GENALE DAWA	Main station	MS145	Bidire	U. Genale	558 506,59	631 470,16
GENALE DAWA	Main station	MS146	Bitata	Genale	575 320,16	610 187,77

WATER LEVEL STATIONS						
GENALE DAWA	Main station	MS147	Harodibe		711 703,25	627 569,94
GENALE DAWA	Main station	MS148	Mena	Welmel	585 181,59	688 691,49
GENALE DAWA	Main station	MS149	Mena	Yadot	593 997,90	709 710,61
GENALE DAWA	Main station	MS150	Bidire		598 430,19	660 164,88
GENALE DAWA	Main station	MS151	Harodibe		650 083,06	672 235,25
GENALE DAWA	Main station	MS152	Goro		649 040,06	725 947,19
GENALE DAWA	Main station	MS153	Harodibe		682 095,63	728 930,50
GENALE DAWA	Main station	MS154	Harodibe		699 690,69	681 849,69
GENALE DAWA	Main station	MS155	Harodibe		715 041,19	631 316,25
GENALE DAWA	Main station	MS156	Chereti		741 995,69	616 941,50
GENALE DAWA	Main station	MS157	Filtu	Genale	768 781,42	554 375,53
GENALE DAWA	Main station	MS158	Bekolmag	Genale	805 173,10	501 290,34
GENALE DAWA	Main station	MS159	Burkale	Genale	814 100,68	490 257,43
GENALE DAWA	Main station	MS160	Megado	Mormora	477 853,50	627 835,10
GENALE DAWA	Main station	MS161	Kibre Mengist	Awata	492 251,74	652 150,86
GENALE DAWA	Main station	MS162	Wadera		525 354,06	636 174,06

WATER LEVEL STATIONS						
GENALE DAWA	Main station	MS163	Dawa		510 736,85	590 267,94
GENALE DAWA	Main station	MS164	Dawa		476 661,63	588 721,38
GENALE DAWA	Main station	MS165	Dawa		462 998,84	577 299,81
GENALE DAWA	Main station	MS166	Dawa		464 949,25	565 028,38
GENALE DAWA	Main station	MS167	Arero		451 884,66	540 534,13
GENALE DAWA	Main station	MS168	Hudat	Dawa	535 480,48	538 302,73
GENALE DAWA	Main station	MS169	Hudat		566 033,13	519 141,06
GENALE DAWA	Main station	MS170	Filtu		646 818,19	532 950,13
GENALE DAWA	Main station	MS171	Bore	U. Dawa	450 239,48	701 544,82
GENALE DAWA	Main station	MS172	El Gof		527 291,94	416 913,22
GENALE DAWA	Main station	MS270	Melda	Dawa	839 051,24	460 920,50
GENALE DAWA	Secondary station	SE272	Ginir	Dinik	680 012,49	787 331,93
GENALE DAWA	Secondary station	SE283	Selka	Mana	651 325,54	776 180,94
GENALE DAWA	Secondary station	SE284	Mena	Shawe	575 195,87	710 788,06
GENALE DAWA	Secondary station	SE286	Mena	Halgol	591 802,03	699 757,02
GENALE DAWA	Secondary station	SE287	Dinshu	Dimtu	591 643,90	792 624,70

WATER LEVEL STATIONS						
GENALE DAWA	Secondary station	SE288	Goba Robe	Tegona	607 142,50	773 859,40
GENALE DAWA	Secondary station	SE290	Goro	Weyib	678 942,50	777 374,94
GENALE DAWA	Secondary station	SE293	Goba Robe	Tegona	608 247,16	773 861,69
GENALE DAWA	Secondary station	SE400	Ginir	Tebel	691 034,43	794 007,87
GENALE DAWA	Transboundary	TB008	Melka Mari	Dawa	696 554,29	475 766,26
GENALE DAWA	Transboundary	TB018	Melda		878 259,46	465 516,65
GENALE DAWA	Transboundary	TB019	Dekewat		609 911,06	435 682,44
GENALE DAWA	Transboundary	TB025	Melda		842 024,03	463 388,81
MAINBV	TYPE	NUMBRLI	TOWN_NAME	RIVER_NAME	EASTING	NORTHING
MEREB	Secondary station	SE295	Bizet	Durumrumo	530 187,18	1 589 771,40
MEREB	Transboundary	TB020	Rama	Mereb	473 350,34	1 598 476,77
MEREB	Transboundary	TB021	Yirga	Mereb	379 789,15	1 634 497,99
OMO GIBE	Lake	LK021	Omorate		176 386,89	501 206,98
OMO GIBE	Main station	MS220	Seyo	Ghibe	299 706,25	960 545,79
OMO GIBE	Main station	MS221	Dire Godu	Ghibe	320 540,63	931 103,84
OMO GIBE	Main station	MS222	Abelti	Great Ghb	343 590,65	910 002,34

WATER LEVEL STATIONS						
OMO GIBE	Main station	MS223	Tedele	Walga	345 832,95	921 053,07
OMO GIBE	Main station	MS224	Welkite	Wabi	364 528,81	912 144,59
OMO GIBE	Main station	MS225	Gibe	Gilgel G.	299 284,45	857 090,12
OMO GIBE	Main station	MS226	Areka	Weyibo	358 641,52	784 998,73
OMO GIBE	Main station	MS227	Areka	Sana	348 733,38	796 084,96
OMO GIBE	Main station	MS228	Medula		323 298,06	817 362,19
OMO GIBE	Main station	MS229	Soyema		257 368,78	802 340,19
OMO GIBE	Main station	MS230	Deri	Gojeb	210 786,67	821 033,23
OMO GIBE	Main station	MS231	Waka	Omo-Ghibe	306 383,83	747 428,13
OMO GIBE	Main station	MS232	Laska		237 799,98	734 071,60
OMO GIBE	Main station	MS233	Felege Selam		207 380,96	746 423,59
OMO GIBE	Main station	MS234	Bachuma		180 760,21	729 360,56
OMO GIBE	Main station	MS235	Hana		176 328,59	705 252,36
OMO GIBE	Main station	MS236	Mago National Park	Omo	165 671,93	651 172,10
OMO GIBE	Main station	MS237	Jinka	Mago	199 064,76	646 575,10
OMO GIBE	Main station	MS238	Fejel		213 292,19	525 482,74

WATER LEVEL STATIONS						
OMO GIBE	Main station	MS239	Gesuba	Deme	336 389,28	733 090,98
OMO GIBE	Main station	MS240	Welde Hane		318 742,02	807 564,80
OMO GIBE	Secondary station	SE232	Jimma	Awaitu	260 623,84	848 421,36
OMO GIBE	Secondary station	SE233	Areka	Sokie	358 656,84	790 527,43
OMO GIBE	Secondary station	SE234	Areka	Ajancho	358 650,70	788 315,95
OMO GIBE	Secondary station	SE236	Welkite	Rebu	365 664,36	923 198,94
OMO GIBE	Secondary station	SE238	Gubre	Megecha	367 810,29	904 394,20
OMO GIBE	Secondary station	SE239	Indibir	Gogheb	378 803,42	895 516,97
OMO GIBE	Secondary station	SE243	Gent	Ghibe	271 895,64	895 933,81
OMO GIBE	Secondary station	SE244	Seka	Seka	251 754,16	840 722,56
OMO GIBE	Secondary station	SE245	Botor Keta	Wedessa	318 338,09	931 113,08
OMO GIBE	Secondary station	SE246	Sekoru	Bidru Awa	323 624,90	875 793,14
OMO GIBE	Secondary station	SE247	Bako	Ghibe	285 699,27	1 008 697,27
OMO GIBE	Secondary station	SE248	Sheboka	Amara	294 471,29	1 004 226,22
OMO GIBE	Secondary station	SE249	Dire Godu	Werabessa	329 354,96	932 173,96
OMO GIBE	Secondary station	SE250	Jimma	Kito	260 640,66	851 740,16

WATER LEVEL STATIONS						
OMO GIBE	Secondary station	SE251	Jimma	Awaitu	260 629,44	849 527,62
OMO GIBE	Secondary station	SE252	Dara	Woshi	170 940,73	810 215,04
OMO GIBE	Secondary station	SE253	Tedele	Kulit	353 580,09	932 084,69
OMO GIBE	Secondary station	SE254	Dire Godu	Darghe	337 050,66	928 826,40
OMO GIBE	Secondary station	SE255	Dire Godu	Nono	337 063,20	932 144,08
OMO GIBE	Secondary station	SE256	Boneya	Bulbul	288 163,25	837 228,89
OMO GIBE	Secondary station	SE257	Anderacha	Gecha	193 008,62	804 539,62
OMO GIBE	Secondary station	SE258	Anderacha	Sheta	194 120,53	805 639,58
OMO GIBE	Secondary station	SE259	Chiri	Guma	196 243,91	791 238,74
OMO GIBE	Secondary station	SE260	Anderacha	Dincha	199 592,89	796 752,48
OMO GIBE	Secondary station	SE261	Morka	Mazie	300 924,54	711 088,37
OMO GIBE	Secondary station	SE263	Areka	Shopa	358 641,52	784 998,73
OMO GIBE	Secondary station	SE264	Gesuba	Gogara	337 524,68	743 039,95
OMO GIBE	Secondary station	SE265	Jinka	Neri	228 681,16	641 682,70
OMO GIBE	Secondary station	SE266	Gibe	Upper Ghi	299 284,45	857 090,12
OMO GIBE	Secondary station	SE267	Seka	Ghibe	244 026,92	840 763,34

WATER LEVEL STATIONS						
OMO GIBE	Secondary station	SE269	Tibe	Legesama	299 940,85	998 667,73
OMO GIBE	Secondary station	SE299	Otolo	L. Abaya	291 950,68	676 833,65
OMO GIBE	Transboundary	TB006	Omorate		163 502,97	519 311,41
RIFT VALLY	Lake	LK013	Arba Minch	Lake Abay	348 402,15	676 662,91
RIFT VALLY	Lake	LK014	Gidicho	Lake Abay	383 878,23	707 540,38
RIFT VALLY	Lake	LK015	Awassa	L. Awassa	439 257,51	779 311,98
RIFT VALLY	Lake	LK016	Bulbula	Lake Abya	461 408,24	839 190,30
RIFT VALLY	Lake	LK017	Bulbula	La.Langan	467 874,25	842 204,32
RIFT VALLY	Lake	LK018	Ziway	Lake Ziwa	472 443,45	873 250,99
RIFT VALLY	Lake	LK019	Dimeka		270 078,73	520 669,54
RIFT VALLY	Lake	LK020	Arsi Negele		446 596,39	825 728,46
RIFT VALLY	Lake	LK102	Arba Minch	Lake Cham	337 277,71	655 682,32
RIFT VALLY	Main station	MS205	Gewada	Weito	281 701,47	593 915,09
RIFT VALLY	Main station	MS206	Beto		271 743,59	665 757,44
RIFT VALLY	Main station	MS207	Gemole	Sagan	339 301,58	578 273,62
RIFT VALLY	Main station	MS208	Arba Minch	K.&A.Outl	341 717,89	660 093,77

WATER LEVEL STATIONS						
RIFT VALLY	Main station	MS209	Chelelektu		386 569,81	666 026,44
RIFT VALLY	Main station	MS210	Gidicho		400 378,91	723 196,25
RIFT VALLY	Main station	MS211	Gelcha		382 533,72	730 029,31
RIFT VALLY	Main station	MS212	Dimtu	Bilate	403 889,75	766 098,67
RIFT VALLY	Main station	MS213	Kulito	Bilate	397 338,60	804 807,67
RIFT VALLY	Main station	MS214	Tora	Djidu	437 128,66	842 330,11
RIFT VALLY	Main station	MS215	Bulbula	Harekelo	466 914,06	847 827,69
RIFT VALLY	Main station	MS216	Adami Tulu	Kekersitu	469 132,94	867 725,48
RIFT VALLY	Main station	MS217	Meki	Meki	481 273,02	900 884,58
RIFT VALLY	Main station	MS218	Assela-Bekoji		501 250,30	888 615,06
RIFT VALLY	Main station	MS219	Sagure	Ketar	505 512,87	859 976,96
RIFT VALLY	Secondary station	SE298	Kuyera	Melka Oda	458 048,27	798 086,70
RIFT VALLY	Secondary station	SE300	Degaga	Boku-Weld	474 625,36	831 240,38
RIFT VALLY	Secondary station	SE301	Teferi Kela	Gidabo	436 968,60	710 773,20
RIFT VALLY	Secondary station	SE302	Degaga	Lepiso	470 212,35	831 242,90
RIFT VALLY	Secondary station	SE303	Dila	Sala	424 802,66	709 682,54

WATER LEVEL STATIONS						
RIFT VALLY	Secondary station	SE304	Kuyera	Tin. Dend	470 195,59	803 605,49
RIFT VALLY	Secondary station	SE305	Wendo Genet	Werka	453 618,11	782 613,56
RIFT VALLY	Secondary station	SE306	Hosaina	Gombera	375 334,33	834 711,73
RIFT VALLY	Secondary station	SE307	Hosaina	Batena	375 334,33	834 711,73
RIFT VALLY	Secondary station	SE310	Kuyera	Dedaba	463 573,12	804 715,37
RIFT VALLY	Secondary station	SE314	Digelu	Upper Tim	527 566,40	856 668,24
RIFT VALLY	Secondary station	SE315	Sagure	Lower Tim	516 542,53	848 924,52
RIFT VALLY	Secondary station	SE316	Asela	Wolkessa	514 326,60	882 089,08
RIFT VALLY	Secondary station	SE317	Sagure	Ashebeka	516 542,53	848 924,52
RIFT VALLY	Secondary station	SE319	Degaga	Gedemso	485 656,20	825 708,38
RIFT VALLY	Secondary station	SE321	Ogokho	Katar	505 509,02	892 036,81
RIFT VALLY	Secondary station	SE323	Asela	Chiufa	507 714,32	882 087,48
RIFT VALLY	Secondary station	SE324	Dalocha	Ferfuro	402 958,28	854 549,37
RIFT VALLY	Secondary station	SE325	Arba Minch	Lake Abay	345 053,27	665 613,97
RIFT VALLY	Secondary station	SE331	Awassa	Tukur Woh	442 574,53	782 624,72
RIFT VALLY	Secondary station	SE333	Arguba	Gato	326 140,93	632 490,37

WATER LEVEL STATIONS						
RIFT VALLY	Secondary station	SE334	Yirga Alem	Gidabo	431 483,26	746 155,95
RIFT VALLY	Secondary station	SE335	Arba Minch	Hare	345 067,50	671 142,72
RIFT VALLY	Secondary station	SE336	Arba Minch	Kulfo	337 307,27	666 740,11
RIFT VALLY	Secondary station	SE337	Arba Minch	40 Spring	339 512,45	663 416,87
RIFT VALLY	Secondary station	SE338	Wendo Genet	Wosha	459 139,84	782 608,86
RIFT VALLY	Secondary station	SE339	Awassa	L.Chelekl	446 991,98	782 619,97
RIFT VALLY	Secondary station	SE340	Awassa	Tukur Woh	444 785,64	784 833,32
RIFT VALLY	Secondary station	SE341	Aleta Wendo	Kola	433 677,37	732 887,06
RIFT VALLY	Secondary station	SE342	Yirga Chefe	Upper Gel	409 273,13	679 855,50
RIFT VALLY	Secondary station	SE343	Gelcha	Hamassa	369 543,09	726 368,00
RIFT VALLY	Secondary station	SE344	Fonko	Weira/Bat	380 859,39	838 014,80
RIFT VALLY	Secondary station	SE345	Butajira	Rinzaf	430 593,61	897 617,97
RIFT VALLY	Secondary station	SE346	Dila	Bedessa	422 584,84	705 263,44
RIFT VALLY	Secondary station	SE347	Tebela	Hamassa	361 830,76	737 443,84
RIFT VALLY	Secondary station	SE349	Hosaina	Guder	375 334,33	834 711,73
TEKEZE	Main station	MS249	Shiraro		349 094,00	1 552 241,03

WATER LEVEL STATIONS						
TEKEZE	Main station	MS250	May Tsamri	Tekeze	413 504,96	1 518 009,31
TEKEZE	Main station	MS251	Mahbere Tsige		459 287,97	1 505 609,32
TEKEZE	Main station	MS252	Yechilay	Tekeze	472 928,08	1 475 855,07
TEKEZE	Main station	MS253	Kedamit		463 588,06	1 424 855,15
TEKEZE	Main station	MS254	Siska		441 120,63	1 391 097,03
TEKEZE	Main station	MS255	Debre Zebit		445 080,71	1 340 393,37
TEKEZE	Main station	MS256	Deresge		414 871,91	1 409 587,88
TEKEZE	Main station	MS257	Sekota		519 906,00	1 397 189,50
TEKEZE	Main station	MS258	Sekota		495 655,52	1 432 869,31
TEKEZE	Main station	MS259	Abiy Adi	Gheba	503 247,01	1 489 112,40
TEKEZE	Main station	MS260	Mekele	Gheba	541 106,75	1 503 521,07
TEKEZE	Main station	MS261	Wukro	Genfel	564 851,17	1 525 688,48
TEKEZE	Main station	MS262	Idaga Arbi	Worie	502 161,21	1 531 137,24
TEKEZE	Main station	MS263	Densha	Mekezo	280 317,68	1 498 871,53
TEKEZE	Main station	MS264	Dansha	Angereb	293 420,86	1 463 687,77
TEKEZE	Main station	MS265	Densha		276 562,91	1 522 597,50

WATER LEVEL STATIONS						
TEKEZE	Main station	MS266	Wehini	Gendawoha	220 944,34	1 410 871,35
TEKEZE	Main station	MS267	Wagna	Atbara	235 926,64	1 416 215,08
TEKEZE	Main station	MS268	Kola Diba	Angereb	336 210,05	1 448 528,16
TEKEZE	Secondary station	SE296	Shiraro	Indaasa	373 825,42	1 584 542,05
TEKEZE	Secondary station	SE297	Shiraro	Mehaquan	368 514,66	1 600 056,82
TEKEZE	Secondary station	SE355	Senkata	Sulluh	554 000,67	1 545 571,33
TEKEZE	Secondary station	SE357	Kwiha	Dolo	559 521,91	1 492 496,61
TEKEZE	Secondary station	SE359	Abiy Adi	Illala	500 000,00	1 494 641,73
TEKEZE	Secondary station	SE360	Kwiha	Metere	554 121,95	1 486 955,33
TEKEZE	Secondary station	SE362	Adi Abun	May Dungu	489 210,32	1 569 847,81
TEKEZE	Secondary station	SE363	Adwa	May Midim	485 968,50	1 561 001,66
TEKEZE	Secondary station	SE364	Axum	Ayehida	475 170,68	1 556 586,06
TEKEZE	Secondary station	SE365	Adi Da-iro	Sebtta	399 638,94	1 566 727,00
TEKEZE	Secondary station	SE366	Shiraro	Molge	365 250,86	1 594 543,12
TEKEZE	Secondary station	SE367	Ambalage	Atsela	556 405,97	1 429 451,98
TEKEZE	Secondary station	SE368	Zarima	Zarema	378 928,52	1 474 271,55

WATER LEVEL STATIONS						
TEKEZE	Secondary station	SE374	Debark	Asera	378 597,31	1 450 675,50
TEKEZE	Secondary station	SE375	Mahbere Tsige	Buya	458 879,49	1 494 673,61
TEKEZE	Transboundary	TB001	Birkuta	Tekeze	324 814,92	1 590 121,19
TEKEZE	Transboundary	TB022	Humera	Tekeze	243 230,89	1 580 009,26
TEKEZE	Transboundary	TB023	Abderafi	Angareb	226 411,16	1 521 514,23
TEKEZE	Transboundary	TB024	Metema	Goang	194 083,58	1 438 830,24
WABI SHEBELE	Main station	MS173	Dodola	Wabi	503 313,39	775 959,90
WABI SHEBELE	Main station	MS174	Hako		544 596,63	790 182,31
WABI SHEBELE	Main station	MS175	Gena	U. Wabishebele	600 446,38	830 789,03
WABI SHEBELE	Main station	MS176	Sede		607 282,50	826 820,25
WABI SHEBELE	Main station	MS177	Seru		651 540,75	875 019,38
WABI SHEBELE	Main station	MS178	Chancho		653 263,50	893 234,94
WABI SHEBELE	Main station	MS179	Shek Husen	U. Wabishebele	691 132,21	873 449,89
WABI SHEBELE	Main station	MS180	Legehida		732 607,44	900 568,88
WABI SHEBELE	Main station	MS181	Majo Weldya		751 927,25	946 451,13
WABI SHEBELE	Main station	MS182	Majo Weldya		749 330,06	932 026,25

WATER LEVEL STATIONS						
WABI SHEBELE	Main station	MS183	Lega Hida	U. Wabishebele	779 342,81	888 574,83
WABI SHEBELE	Main station	MS184	Majo Weldya		804 586,94	929 893,31
WABI SHEBELE	Main station	MS185	Fik		841 147,06	948 953,56
WABI SHEBELE	Main station	MS186	Fik		843 030,44	913 265,94
WABI SHEBELE	Main station	MS187	Hamero		835 552,00	840 581,06
WABI SHEBELE	Main station	MS188	Jara		731 670,38	833 740,50
WABI SHEBELE	Main station	MS189	Hamero		845 774,56	810 704,13
WABI SHEBELE	Main station	MS190	Fik		895 611,81	956 775,38
WABI SHEBELE	Main station	MS191	Segeg		911 329,19	864 965,69
WABI SHEBELE	Main station	MS192	Hamero		860 219,75	811 499,13
WABI SHEBELE	Main station	MS193	Hamarro Hadad	Wabishebele	857 494,06	798 326,62
WABI SHEBELE	Main station	MS194	Imi		836 954,00	753 435,31
WABI SHEBELE	Main station	MS195	Imi		850 381,31	715 412,19
WABI SHEBELE	Main station	MS196	Gode	Wabi	960 657,91	660 481,64
WABI SHEBELE	Main station	MS197	Kelafo		1 068 646,25	621 864,25
WABI SHEBELE	Main station	MS199	Hadew	Upp. Fafa	895 685,94	1 022 276,34

WATER LEVEL STATIONS

WABI SHEBELE	Main station	MS200	Jijiga	Jijiga	917 555,94	1 035 799,64
WABI SHEBELE	Main station	MS201	Dega Medo	Fafen	976 158,85	896 062,19
WABI SHEBELE	Main station	MS202	Degeh Bur		1 002 172,56	911 308,31
WABI SHEBELE	Main station	MS203	Bircot	Fafen Chef	1 027 121,81	843 694,03
WABI SHEBELE	Main station	MS204	Korahe		1 094 106,13	732 549,25
WABI SHEBELE	Main station	MS271	Mesela		734 719,63	1 008 375,06
WABI SHEBELE	Secondary station	SE289	Agarfa	Weyib	588 292,18	814 730,48
WABI SHEBELE	Secondary station	SE379	Robe	Alkeso	560 629,50	869 966,04
WABI SHEBELE	Secondary station	SE380	Ticho	Einemor	557 329,19	864 434,06
WABI SHEBELE	Secondary station	SE381	Bedesa	Medhaidu	694 630,57	984 261,70
WABI SHEBELE	Secondary station	SE382	Adaba	Lelisso	541 971,69	773 765,83
WABI SHEBELE	Secondary station	SE383	Adaba	Maribo	536 449,04	773 761,66
WABI SHEBELE	Secondary station	SE384	Dodola	Ukuma	505 522,32	775 960,09
WABI SHEBELE	Secondary station	SE386	Asasa	Assassa	524 294,07	784 809,31
WABI SHEBELE	Secondary station	SE387	Ticho	Wolkessa	560 635,30	865 543,81
WABI SHEBELE	Secondary station	SE388	Ticho	Ulul	560 635,30	865 543,81

WATER LEVEL STATIONS						
WABI SHEBELE	Secondary station	SE389	Kelo	Harerghe	560 643,94	858 910,49
WABI SHEBELE	Secondary station	SE390	Robe	Robe	569 451,98	867 767,33
WABI SHEBELE	Secondary station	SE391	Adaba	Herero	535 344,51	773 760,89
WABI SHEBELE	Secondary station	SE392	Adaba	Maribo	540 878,36	759 393,64
WABI SHEBELE	Secondary station	SE393	Adaba	Fruna	546 387,86	775 980,58
WABI SHEBELE	Secondary station	SE394	Alem Maya	L. Alemay	831 713,97	1 040 504,36
WABI SHEBELE	Secondary station	SE395	Alem Maya	Lake Adel	823 990,69	1 043 759,80
WABI SHEBELE	Secondary station	SE396	Harer	Hamaressa	838 378,17	1 032 811,93
WABI SHEBELE	Secondary station	SE397	Harer	Bissidimo	843 876,50	1 032 860,28
WABI SHEBELE	Secondary station	SE398	Hirna	Hirna	730 727,57	1 019 852,62
WABI SHEBELE	Secondary station	SE399	Water	Dawe	807 591,98	1 032 555,59
WABI SHEBELE	Secondary station	SE401	Bisidimo	Upper Ere	857 174,91	1 021 906,64
WABI SHEBELE	Secondary station	SE403	Bedesa	Jawes	695 730,51	984 266,98
WABI SHEBELE	Transboundary	MS198	Ferfer	Wabishebele	1 164 865,79	562 056,72

Annex 2: List of envisaged surface Water Quality station locations

WATER QUALITY STATIONS						
ABBAY	Baseline	BA004	Barir Dar	Abbay	327 537,93	1 285 802,96
ABBAY	Impact	IM001	Debre Zeit	Abbay	86 973,48	1 210 284,91
ABBAY	Impact	IM002	Golo	Uke	230 347,80	1 017 836,92
ABBAY	Impact	IM003	Lemi	Lower Lemi	480 970,29	1 083 275,49
ABBAY	Impact	IM004	Nejo	Giami	121 134,90	1 046 821,08
ABBAY	Impact	IM005	Tsige Maryam	Uke	218 296,85	1 042 877,90
ABBAY	Impact	IM007	Sire	Indris	262 943,32	999 837,48
ABBAY	Impact	IM014	Zege	Gilgel Abay	295 725,40	1 303 692,23
ABBAY	Impact	IM015	Dabi	Talia	327 966,27	1 195 968,76
ABBAY	Impact	IM016	Asendabo	Fincha	319 743,19	1 106 337,13
ABBAY	Impact	IM017	Fincha-a	Fincha	316 704,03	1 058 115,91
ABBAY	Impact	IM018	Mendida	Robi	526 875,78	1 060 048,29
ABBAY	Impact	IM019	Arjo	Didessa	187 479,53	999 812,26
ABBAY	Impact	IM020	Ageyo	Upper Didessa	220 971,51	890 158,93
ABBAY	Impact	IM021	Godere	Dabus	67 631,97	1 149 371,96
ABBAY	Impact	IM022		Ternch	288 207,26	1 138 844,94

WATER QUALITY STATIONS						
ABBAY	Impact	IM027	Ambo	Guder	389 149,30	996 464,53
ABBAY	Impact	IM029	Ambo	Guder	360 505,76	999 833,76
ABBAY	Impact	IM030	Azezo-Gonder	Megech	331 299,29	1 380 102,80
ABBAY	Impact	IM033	Bahir Dar	Abbay	336 603,77	1 273 238,86
ABBAY	Impact	IM034	before Ibnat	Upper Ribb	388 301,22	1 332 334,72
ABBAY	Impact	IM035	Werota	Ribb	346 263,82	1 326 235,66
ABBAY	Impact	IM036	Forae Iyesus	Beles	265 643,63	1 298 768,40
ABBAY	Impact	IM037	Robit	Megech	322 395,16	1 356 258,44
ABBAY	Impact	IM038	Dangla-Durbete	Gilgel Abbay	277 455,34	1 251 138,63
ABBAY	Impact	IM047	Debre Markos		364 163,94	1 138 163,63
ABBAY	Impact	IM065	Fiche		477 964,48	1 093 031,73
ABBAY	Impact	IM067	Debre Markos		363 064,72	1 152 627,37
ABBAY	Impact	IM068	Debre Birhan	Beressa	555 848,14	1 079 200,11
ABBAY	Impact	IM069	Debre Birhan	Beressa	572 044,62	1 066 715,24
ABBAY	Impact	IM070	Wanzaye Megenteya	Gumara	351 345,69	1 309 757,91
ABBAY	Lake	LA001			316 277,96	1 057 995,67

WATER QUALITY STATIONS						
ABBAY	Lake	LA012			317 326,83	1 329 193,84
ABBAY	Transboundary	TB004	Bambudi	Abbay	64 073,83	1 245 536,47
ABBAY	Trend	TR010	Ajibar	Abbay	448 037,75	1 200 387,97
ABBAY	Trend	TR011	Dejen-Goha Tsion	Abbay	411 096,25	1 113 950,43
ABBAY	Trend	TR012	Kuch	Abbay	283 008,05	1 138 350,52
ABBAY	Trend	TR013	Abbay	Abbay	126 922,46	1 113 511,98
ABBAY	Trend	TR014	Abatimbo El Gumas	Abbay	80 133,81	1 179 237,54
AWASH	Baseline	BA005	Holota Genet	Holeta (U. Awash)	444 753,31	1 009 562,26
AWASH	Impact	IM006	Melka Sedi	Middle Awash	625 564,92	1 010 213,86
AWASH	Impact	IM008	Nazreth	Upper Awash	518 598,04	937 008,62
AWASH	Impact	IM011	dubti	Lower Awash	767 311,63	1 277 874,27
AWASH	Impact	IM028	Dubti	Awash	735 435,65	1 291 615,47
AWASH	Impact	IM031	Adis Hiywet	Awash	536 620,90	928 987,50
AWASH	Impact	IM039	Burayu	Little Akaki	458 912,90	1 005 818,90
AWASH	Impact	IM040	Sendafa?	Akaki	490 986,14	1 014 275,51
AWASH	Impact	IM041	Akaki Beseka	Little Akaki	470 979,04	977 664,57

WATER QUALITY STATIONS

AWASH	Impact	IM058	Kemissie	Borkena	601 801,25	1 175 078,07
AWASH	Impact	IM071	Kombolcha	Borkena	581 950,09	1 220 615,97
AWASH	Impact	IM072	Dessie	Borkena	567 831,32	1 240 556,27
AWASH	Lake	LA002			502 758,59	928 727,34
AWASH	Lake	LA013			663 085,56	1 128 558,19
Awash	Lake	LA014			740 802,87	1 208 055,29
AWASH	Lake	LA015			803 095,37	1 235 345,34
AWASH	Lake	LA016			821 486,49	1 203 309,19
AWASH	Lake	LA017			791 230,14	1 277 466,93
AWASH	Trend	TR015	Melka kunture	U. Awash	456 011,70	962 470,10
AWASH	Trend	TR016a & TR016b	Akaki Beseka	Great & Little Akaki	473 660,40	975 086,34
AWASH	Trend	TR017	Koka	U. Awash	501 199,90	929 245,99
AWASH	Trend	TR018	Adis Hiywet	Awash	561 472,48	939 888,73
AWASH	Trend	TR019	Metahra	Middle Awash	611 203,20	977 965,97
AWASH	Trend	TR020	Algeyta	Middle Awash	643 387,20	1 053 711,52

WATER QUALITY STATIONS						
AWASH	Trend	TR021	Gewane	Awash	669 556,96	1 130 015,31
AWASH	Trend	TR022	Gewane	L. Awash	673 694,88	1 131 378,25
AWASH	Trend	TR023	Adaitu	L. Awash	691 207,03	1 229 892,58
AWASH	Trend	TR024	Dubti	Awash	719 956,15	1 294 943,03
AWASH	Trend	TR025	Near Dubti	Lower Awash	786 747,88	1 272 563,16
BARO AKOBO	Baseline	BA006	Supe	Geba	131 368,64	939 267,41
BARO AKOBO	Baseline	BA007	Abobo	Alwero	21 789,94	860 808,71
BARO AKOBO	Baseline	BA008	Punydo	Gilo	1 518,88	830 991,22
BARO AKOBO	Impact	IM026	Periet	GIlo	-61 440,74	862 822,38
BARO AKOBO	Impact	IM032	Gambella	Baro	20 952,51	908 125,52
BARO AKOBO	Impact	IM044	Gambella	Baro	1 923,54	913 851,10
BARO AKOBO	Impact	IM048	Metu		129 282,26	918 324,34
BARO AKOBO	Impact	IM054	Welkite	Wabi	98 482,95	772 317,79
BARO AKOBO	Impact	IM073	Metu		116 532,26	925 915,45
BARO AKOBO	Transboundary	TB005	Jikao	Baro	-74 381,52	928 149,09
BARO AKOBO	Trend	TR026	Seriti	Baro	51 424,45	908 231,07

WATER QUALITY STATIONS						
BARO AKOBO	Trend	TR027	Itang	Baro	-32 642,66	906 394,30
BARO AKOBO	Trend	TR028	Abobo	Alwero	3 929,95	872 508,83
DENAKIL	Lake	LA019			707 100,31	1 467 412,71
DENAKIL	Lake	LA020			766 144,92	1 376 603,61
DENAKIL	Lake	LA018			642 076,51	1 569 059,11
GENALE DAWA	Baseline	BA010	Dinshu	U. Weyb	583 083,68	781 502,23
GENALE DAWA	Baseline	BA011	Bore	U. Dawa	450 239,48	701 544,82
GENALE DAWA	Impact	IM009	Mena	Yadot	593 536,45	709 876,85
GENALE DAWA	Impact	IM010	Mena	Yadot	805 781,94	501 970,52
GENALE DAWA	Impact	IM012	Robe	Weyib	609 818,83	816 394,86
GENALE DAWA	Impact	IM059	Robe	Shaya	606 407,13	779 242,44
GENALE DAWA	Impact	IM060	Robe	Shaya	610 442,85	801 180,28
GENALE DAWA	Transboundary	TB007	Dolo Odo	Genale	842 024,03	463 388,81
GENALE DAWA	Transboundary	TB008	Melka Mari	Dawa	696 554,29	475 766,26
GENALE DAWA	Trend	TR033	Arbe Goba	U. Genale	465 287,25	751 362,29
GENALE DAWA	Trend	TR034	Bidire	U. Genale	558 506,59	631 470,16

WATER QUALITY STATIONS						
GENALE DAWA	Trend	TR035	Filtu	Genale	768 781,42	554 375,53
GENALE DAWA	Trend	TR036	Goro	Weyib	686 295,42	771 859,43
GENALE DAWA	Trend	TR037	Ara Terra	Weyb	743 469,34	719 133,96
GENALE DAWA	Trend	TR038	El-Medo	Weyb	808 807,66	623 707,52
GENALE DAWA	Trend	TR039	Lema Shilindi	Weyb	846 581,90	534 855,20
GENALE DAWA	Trend	TR040	Shakiso	Dawa	491 707,80	639 598,10
GENALE DAWA	Trend	TR041	Melka Guba	Dawa	534 644,38	537 563,57
MEREB	Baseline	BA001	Bizet	Durumrumo	531 199,48	1 582 119,65
MEREB	Trend	TR001	Rama	Mereb	473 350,34	1 598 476,77
MEREB	Trend	TR002	Yirga	Mereb	379 789,15	1 634 497,99
OMO GIBE	Baseline	BA009	Bako	Ghibe	286 092,27	1 013 843,93
OMO GIBE	Impact	IM023	Jinka	Mago	199 064,76	646 575,10
OMO GIBE	Impact	IM024	Toley	Ghibe	320 848,30	932 441,05
OMO GIBE	Impact	IM049	Welkite	Wabi	374 804,47	914 392,58
OMO GIBE	Impact	IM050	Welkite	Wabi	355 542,63	911 473,39
OMO GIBE	Impact	IM051	Jimma	Gilgel Gibe	268 445,14	840 798,06

WATER QUALITY STATIONS						
OMO GIBE	Impact	IM061	Jinka	Neri	232 550,74	649 591,33
OMO GIBE	Impact	IM064	Jinka	Neri	224 635,01	631 411,89
OMO GIBE	Impact	IM074	Jimma	Gilgel Gibe	250 594,54	841 625,15
OMO GIBE	Lake	LA011			181 789,31	512 359,33
OMO GIBE	Transboundary	TB006	Kelem	Omo	163 502,97	519 311,41
OMO GIBE	Trend	TR029	Seyo	Ghibe	299 706,25	960 545,79
OMO GIBE	Trend	TR030	Abelti	Great Ghibe	343 062,22	909 699,95
OMO GIBE	Trend	TR031	Waka	Omo-Ghibe	306 383,83	747 428,13
OMO GIBE	Trend	TR032	Mago National Park	Omo	165 671,93	651 172,10
RIFT VALLY	Impact	IM052	Hosaina	Gombera	375 370,49	843 191,36
RIFT VALLY	Impact	IM053	Hosaina		377 606,67	822 769,48
RIFT VALLY	Impact	IM055	Dila	Bedessa	423 002,12	698 662,82
RIFT VALLY	Impact	IM056	Arba minch		334 675,35	674 771,70
RIFT VALLY	Impact	IM066	Dila		414 873,60	713 696,17
RIFT VALLY	Impact	IM075	Assela-Bekoji		501 250,30	888 615,06
RIFT VALLY	Impact	IM076	Arba Minch		344 702,88	664 788,25

WATER QUALITY STATIONS						
RIFT VALLY	Lake	LA003			471 738,19	872 525,42
RIFT VALLY	Lake	LA004			468 005,24	846 782,57
RIFT VALLY	Lake	LA005			460 265,06	846 540,70
RIFT VALLY	Lake	LA006			435 583,77	832 479,09
RIFT VALLY	Lake	LA007			442 195,48	783 124,97
RIFT VALLY	Lake	LA008			380 744,65	727 821,73
RIFT VALLY	Lake	LA009			336 369,71	650 672,41
RIFT VALLY	Lake	LA010			276 677,85	533 615,88
TEKEZE	Baseline	BA002	Sekota	Upper Tekeze	537 241,53	1 389 569,02
TEKEZE	Baseline	BA003	Gonder-Tikildingay	Atbara	322 417,29	1 407 108,99
TEKEZE	Impact	IM013	Humera	Tekeze	239 433,86	1 580 520,13
TEKEZE	Impact	IM046	Adigrat		548 625,71	1 567 474,07
TEKEZE	Impact	IM062	Sekota		495 655,52	1 432 869,31
TEKEZE	Transboundary	TB001	Birkuta	Tekeze	324 814,92	1 590 121,19
TEKEZE	Transboundary	TB002	Abderafi	Angereb	227 621,38	1 516 376,42
TEKEZE	Transboundary	TB003	Metema	Atbara	196 750,94	1 436 249,20

WATER QUALITY STATIONS						
TEKEZE	Trend	TR003	Wukro	Genfel	564 984,45	1 525 548,10
TEKEZE	Trend	TR004	Abiy Adi	Gheba	503 317,22	1 487 390,92
TEKEZE	Trend	TR005	Togo ber	Tekeze	412 728,90	1 517 898,00
TEKEZE	Trend	TR006		Tekeze	349 094,00	1 552 241,03
TEKEZE	Trend	TR007	Kola Diba	Angereb	336 210,05	1 448 528,16
TEKEZE	Trend	TR008	Dansha	Angereb	293 420,86	1 463 687,77
TEKEZE	Trend	TR009	Wagna	Atbara	235 672,02	1 416 401,74
WABI SHEBELE	Baseline	BA012	Gena	U. Wabishebele	600 446,38	830 789,03
WABI SHEBELE	Baseline	BA013	Guresa Terara	Fafen	896 643,21	1 023 437,39
WABI SHEBELE	Baseline	BA014	Jijiga	Jerer	914 394,29	1 045 059,28
WABI SHEBELE	Impact	IM025	Mustahil	Wabishebele	1 142 154,29	576 523,67
WABI SHEBELE	Impact	IM042	Jijiga	Jerer	920 599,58	1 026 301,36
WABI SHEBELE	Impact	IM043	Harer	Hamaressa	836 239,26	1 021 809,10
WABI SHEBELE	Impact	IM045	Harer	Hamaressa	840 063,79	1 037 635,03
WABI SHEBELE	Impact	IM057	Gode	Wabishebele	996 387,55	659 480,64
WABI SHEBELE	Impact	IM063	Degeh Bur	Jerer	995 643,53	918 709,23

WATER QUALITY STATIONS						
WABI SHEBELE	Impact	IM077	Kebridahar	Fafen	1 079 711,06	756 174,13
WABI SHEBELE	Transboundary	TB009	Ferfer	Wabishebele	1 164 865,79	562 056,72
WABI SHEBELE	Trend	TR042	Shek Husen	U. Wabishebele	691 132,21	873 449,89
WABI SHEBELE	Trend	TR043	Lega Hida	U. Wabishebele	779 342,81	888 574,83
WABI SHEBELE	Trend	TR044	Hamarro Hadad	Wabishebele	857 494,06	798 326,62
WABI SHEBELE	Trend	TR045	Imi	Wabishebele	857 499,03	712 158,58
WABI SHEBELE	Trend	TR046		Wabishebele	1 017 352,39	650 586,73
WABI SHEBELE	Trend	TR047	Dega Medo	Fafen	976 158,85	896 062,19
WABI SHEBELE	Trend	TR048	Degaha Bur	Jerer	1 009 777,07	904 614,62
WABI SHEBELE	Trend	TR049	Bircot	Fafen Chef	1 027 121,81	843 694,03
WABI SHEBELE	Trend	TR050	Kebridehar	Fafen	1 090 905,75	739 925,83
WABI SHEBELE	Trend	TR051	Shilabo	Fafen Chef	1 120 129,89	628 573,51

Annex 3: List of envisaged Surface water Sediment station locations

WATER QUALITY STATIONS					
MAINBV	NUMBRLI	TOWN_NAME	RIVER_NAME	EASTING	NORTHING
ABBAY	MS008	Dejen-Goha Tsion	Abbay	411 096,25	1 113 950,43
ABBAY	MS015	Guder	Debis	364 803,29	997 290,86
ABBAY	MS016	Asendabo	Fincha	319 743,19	1 106 337,13
ABBAY	MS017	Fincha-a	Fincha	316 704,03	1 058 115,91
ABBAY	MS018	Ageyo	Didessa	221 128,79	888 474,91
ABBAY	MS023	Arjo	Didessa	187 479,53	999 812,26
ABBAY	MS024	Tsige Maryam	Uke	218 296,85	1 042 877,90
ABBAY	MS036	Godere		77 854,91	1 172 826,63
ABBAY	MS037	Abatimbo El Gumas	Abbay	80 133,81	1 179 237,54
ABBAY	TB010	Gizen		39 217,47	1 187 396,38
ABBAY	MS038	Abbay	Abbay	126 922,46	1 113 511,98
ABBAY	TB011	Omedila	Abbay	60 848,41	1 244 414,77
ABBAY	MS050	Kuch	Abbay	283 008,05	1 138 350,52
ABBAY	MS056	Ajibar		448 037,75	1 200 387,97
ABBAY	MS064	Zege	Gilgel Abay	295 725,40	1 303 692,23
ABBAY	MS065	Wetet Abay	Gelgel A.	285 023,16	1 257 619,82

WATER QUALITY STATIONS					
MAINBV	NUMBRLI	TOWN_NAME	RIVER_NAME	EASTING	NORTHING
ABBAY	MS066	Bahr Dar	Abbay	325 551,89	1 282 812,91
ABBAY	MS067	Wanzaye	Gumara	350 757,13	1 308 121,33
ABBAY	MS068	Robit	Megech	322 395,16	1 356 258,44
ABBAY	MS070	Ibnat	Upper Rib	388 978,85	1 332 288,87
ABBAY	TB012	Omedila		92 989,22	1 322 594,17
ABBAY	TB013	Tewodros Ketema		129 829,43	1 386 383,63
ABBAY	TB014	Metema		150 162,31	1 402 603,13
AWASH	MS079	Hayu	Awash	767 214,39	1 277 938,72
AWASH	MS081	Dubti	Awash	731 082,05	1 294 247,81
AWASH	MS083	Tendaho	Awash	712 560,25	1 291 901,54
AWASH	MS087	Jimate	Borkena	601 725,56	1 175 221,15
AWASH	MS089	Gewane	Awash	673 694,88	1 131 378,25
AWASH	MS094	Algeyta	Middle Awash	643 387,20	1 053 711,52
AWASH	MS096	Melka Sede	Awash	623 042,79	1 017 156,03
AWASH	MS099	Metehara	Awash	593 468,35	978 375,33
AWASH	MS100	Adis Hiywet	Awash	563 831,31	942 938,86

WATER QUALITY STATIONS					
MAINBV	NUMBRLI	TOWN_NAME	RIVER_NAME	EASTING	NORTHING
AWASH	MS102	Wenji	Awash	518 618,02	936 730,69
AWASH	MS106	Koka	Awash	502 201,78	928 518,96
AWASH	MS109	Akaki Beseka	Akaki	475 810,95	981 592,52
AWASH	MS111	Holota	Holeta	447 252,34	1 003 731,64
AWASH	MS115	Mile	Awash	694 397,47	1 230 936,70
BARO AKOBO	TB015	Tirgol		-139 472,59	905 269,63
BARO AKOBO	TB016	Tirgol		-136 690,08	925 546,81
BARO AKOBO	TB017	Jikawo		-116 809,51	936 003,44
BARO AKOBO	TB005	Jikawo		-74 370,71	928 153,19
BARO AKOBO	MS118	Itang	Baro	-21 583,55	907 265,74
BARO AKOBO	MS119	Punydo	Gilo	-22 289,96	845 152,26
BARO AKOBO	MS120	Abobo	Alwero	3 929,95	872 508,83
BARO AKOBO	MS121	Gambela	Baro	11 625,12	912 431,54
BARO AKOBO	MS126	Metu		125 408,62	921 284,31
BARO AKOBO	MS127	Supe	Geba	131 074,93	938 955,02
GENALE DAWA	MS134	Dinshu	U. Weyb	583 083,68	781 502,23

WATER QUALITY STATIONS					
MAINBV	NUMBRLI	TOWN_NAME	RIVER_NAME	EASTING	NORTHING
GENALE DAWA	MS137	Goro	Weyib	678 961,57	771 845,45
GENALE DAWA	MS139	Ara Terra	Weyb	743 469,34	719 133,96
GENALE DAWA	MS140	El-Medo	Weyb	808 807,66	623 707,52
GENALE DAWA	MS141	Lema Shilindi	Weyb	846 581,90	534 855,20
GENALE DAWA	MS145	Bidire	U. Genale	558 506,59	631 470,16
GENALE DAWA	MS149	Mena	Yadot	593 997,90	709 710,61
GENALE DAWA	MS157	Filtu	Genale	768 781,42	554 375,53
GENALE DAWA	MS158	Bekolmag	Genale	805 173,10	501 290,34
GENALE DAWA	MS161	Kibre Mengist	Awata	492 251,74	652 150,86
GENALE DAWA	MS168	Hudat	Dawa	535 480,48	538 302,73
GENALE DAWA	TB008	Melka Mari	Dawa	696 554,29	475 766,26
GENALE DAWA	TB018	Melda		878 259,46	465 516,65
GENALE DAWA	MS171	Bore	U. Dawa	450 239,48	701 544,82
GENALE DAWA	TB019	Dekewat		609 911,06	435 682,44
WABI SHEBELE	MS175	Gena	U. Wabishebele	600 446,38	830 789,03
WABI SHEBELE	MS179	Shek Husen	U. Wabishebele	691 132,21	873 449,89

WATER QUALITY STATIONS					
MAINBV	NUMBRLI	TOWN_NAME	RIVER_NAME	EASTING	NORTHING
WABI SHEBELE	MS183	Lega Hida	U. Wabishebele	779 342,81	888 574,83
WABI SHEBELE	MS193	Hamarro Hadad	Wabishebele	857 494,06	798 326,62
WABI SHEBELE	MS195	Imi		850 381,31	715 412,19
WABI SHEBELE	MS196	Gode	Wabi	960 657,91	660 481,64
WABI SHEBELE	MS198	Ferfer	Wabishebele	1 164 865,79	562 056,72
WABI SHEBELE	MS199	Hadew	Upp. Fafa	895 685,94	1 022 276,34
WABI SHEBELE	MS200	Jijiga	Jijiga	917 555,94	1 035 799,64
WABI SHEBELE	MS201	Dega Medo	Fafen	976 158,85	896 062,19
WABI SHEBELE	MS202	Degeh Bur		1 002 172,56	911 308,31
WABI SHEBELE	MS203	Bircot	Fafen Chef	1 027 121,81	843 694,03
WABI SHEBELE	MS204	Korahe		1 094 106,13	732 549,25
RIFT VALLY	MS208	Arba Minch	K.&A.Outl	341 717,89	660 093,77
RIFT VALLY	MS218	Assela-Bekoji		501 250,30	888 615,06
OMO GIBE	MS220	Seyo	Ghibe	299 706,25	960 545,79
OMO GIBE	MS222	Abelti	Great Ghb	343 590,65	910 002,34
OMO GIBE	MS224	Welkite	Wabi	364 528,81	912 144,59

WATER QUALITY STATIONS					
MAINBV	NUMBRLI	TOWN_NAME	RIVER_NAME	EASTING	NORTHING
OMO GIBE	MS231	Waka	Omo-Ghibe	306 383,83	747 428,13
OMO GIBE	MS236	Mago National Park	Omo	165 671,93	651 172,10
OMO GIBE	MS237	Jinka	Mago	199 064,76	646 575,10
OMO GIBE	TB006	Omorate		163 502,97	519 311,41
MEREB	TB020	Rama	Mereb	473 350,34	1 598 476,77
MEREB	TB021	Yirga	Mereb	379 789,15	1 634 497,99
TEKEZE	TB022	Humera	Tekeze	243 230,89	1 580 009,26
TEKEZE	TB001	Birkuta	Tekeze	324 814,92	1 590 121,19
TEKEZE	MS249	Shiraro		349 094,00	1 552 241,03
TEKEZE	MS250	May Tsamri	Tekeze	413 504,96	1 518 009,31
TEKEZE	MS258	Sekota		495 655,52	1 432 869,31
TEKEZE	MS259	Abiy Adi	Gheba	503 247,01	1 489 112,40
TEKEZE	MS261	Wukro	Genfel	564 851,17	1 525 688,48
TEKEZE	MS264	Dansha	Angereb	293 420,86	1 463 687,77
TEKEZE	TB023	Abderafi	Angareb	226 411,16	1 521 514,23
TEKEZE	TB024	Metema	Goang	194 083,58	1 438 830,24

WATER QUALITY STATIONS					
MAINBV	NUMBRLI	TOWN_NAME	RIVER_NAME	EASTING	NORTHING
TEKEZE	MS267	Wagna	Atbara	235 926,64	1 416 215,08
TEKEZE	MS268	Kola Diba	Angereb	336 210,05	1 448 528,16
BARO AKOBO	MS269	Bonga	Baro	44 721,01	908 751,68
GENALE DAWA	TB025	Melda		842 024,03	463 388,81