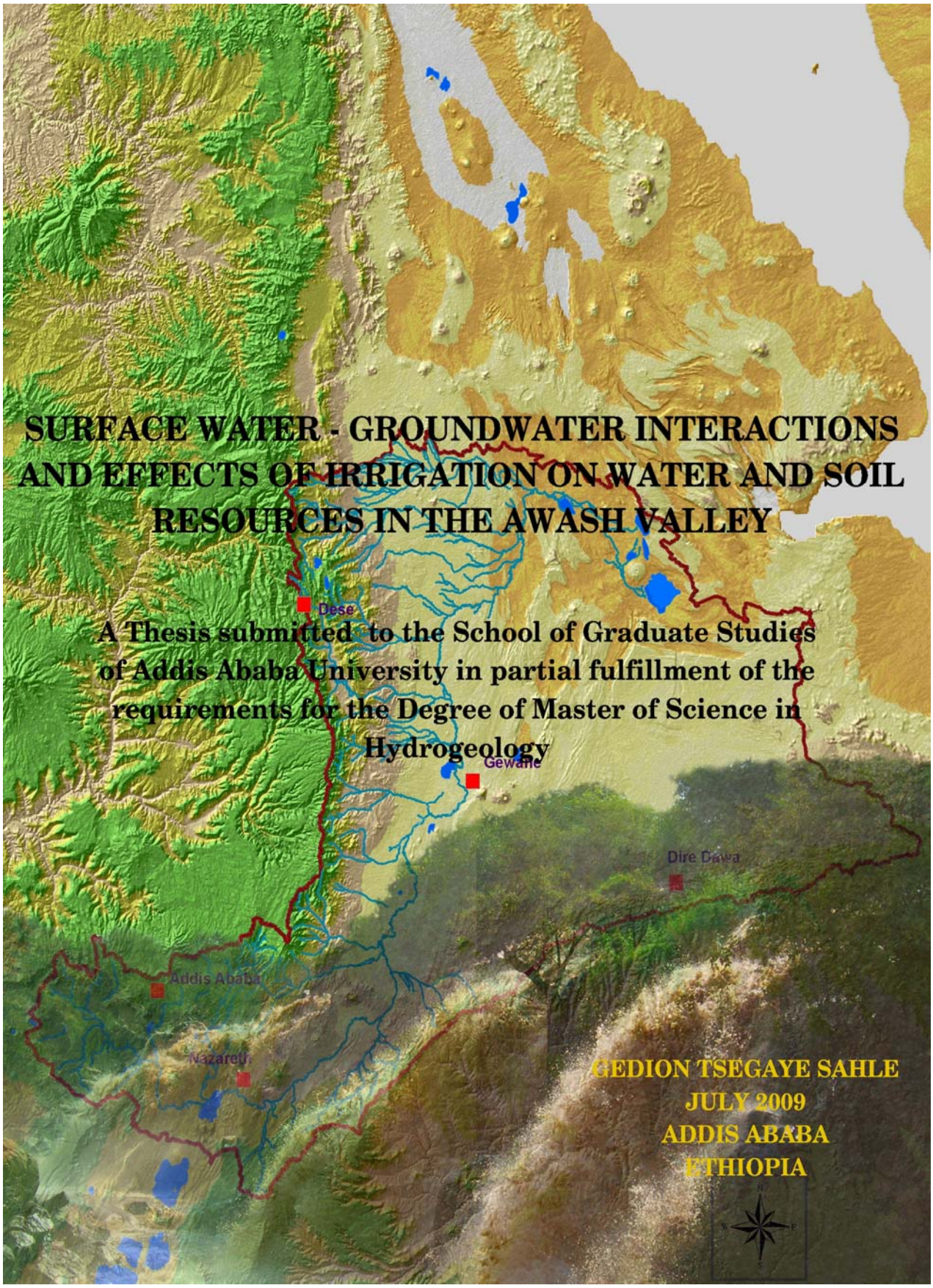


SURFACE WATER - GROUNDWATER INTERACTIONS AND EFFECTS OF IRRIGATION ON WATER AND SOIL RESOURCES IN THE AWASH VALLEY

A Thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of Master of Science in Hydrogeology

GEDION TSEGAYE SAHLE

JULY 2009

ADDIS ABABA

ETHIOPIA



ADDIS ABABA UNIVERSITY
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by Gedion Tsegaye Sahle
July 2009

Approved by Board of Examiners

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Abstract

With an area of some 115,523 km^2, the Awash basin mainly comprises the north-western and south-eastern highlands and the rift valley. The basin is endowed with abundant surface water and groundwater resources that require proper management if they are to be wisely utilized in a sustainable manner. With the Awash river as the major resource, the Awash valley is the most developed part in Ethiopia in terms of irrigated agriculture.

The Awash river water balance has been computed with recent level of irrigation development for a period of five years. The results show that the Awash river is generally influent with transmission loss of some 2.1 BCM and 6.8 BCM for the reaches Koka-Metahara and Metahara-Tendaho respectively during the given period. These values include potential indirect recharge as well as loss due to over-bank flooding and subsequent evaporation. One such place where considerable loss (about 500 MCM/yr from evapotranspiration) occurs is Gedebassa swamp, situated in the middle part of the Metahara - Tendaho reach.

Influent conditions may be valid as groundwater tables are relatively deeper than the Awash river in the valley and highly permeable river bed sub-reaches exist (alluvial sediments and fractured/faulted volcanic rocks). Nevertheless, there are intermediate reaches where the Awash may also be effluent. These include the vicinities of major irrigation schemes and the sub-reach immediately downstream of Koka reservoir where groundwater table is shallow.

The Awash river receives considerable surface runoff inflow (about 2.7 BCM/yr) in the middle and lower valleys, mainly from the western sub-catchments. About 60% of this amount is acquired upstream of Gedebassa swamp and the rest 40% downstream. In the upper valley, the Awash river receives inflow of some 420 MCM/yr, which is less than one-fifth of what is received in the reach between Metahara and Tendaho. And yet, from the overall irrigation abstractions (currently less than 1 BCM/yr), more than 60% take place in the upper valley.

With computed overall irrigation efficiency of less than 45%, the Amibara Irrigation Schemes (AIS) in the middle valley have been studied at semi-detailed level. Groundwater hydrograph analysis based on peizometers' data has shown that surface irrigation in Amibara is responsible for rising groundwater tables with average rates of 0.3 to over 1 m/yr in the 70s up to 90s. Further investigations on possible Awash river-groundwater as well as canal water-groundwater interactions in Amibara have been made possible by conducting groundwater flow analysis. The prepared depth to groundwater map portrays that average groundwater levels are within 3m (shallow depth) in one-third of AIS.

As evidenced from analysis results of bulk water and surface soil samples collected as part of this study, the Awash river is regarded as suitable for irrigation with moderate salinity and low sodicity; the groundwater in Amibara is generally saline (85% of AIS above 5 mS/cm); and about 20% of AIS soils are saline and 3% saline-sodic.

The groundwater levels have currently reached close to surface, due to recharge from irrigation, that evaporation has now become one of the major outputs other than groundwater outflow. The relatively higher evaporation rate in Amibara favours upward movement of salts from the saline, shallow groundwater during the fallow period. In addition, the shallow groundwater has further hindered effective leaching of soluble salts below the root zone, necessitating measures of groundwater level control by sub-surface drainage installation or other means.

CHAPTER ONE

INTRODUCTION

1.1 Background

Undoubtedly, water is the most important natural resource in our world. Concurrently, the need for proper development of this priceless resource is undeniable. Regarding the growing need for water due to population increase and modernization (agricultural development, hydro-power generation, domestic water-supply, etc), various types of studies have been conducted globally, involving different branches of science, on essential aspects of water resources technology. As the availability of surface water and groundwater to required quantity and quality for various purposes varies from place to place, the world has been considering scientific research as one of the powerful tools to bring about constructive change and ensure sustainability.

Scientific research is indispensable to water resources management for a country like Ethiopia, which is endowed with abundant water and land resources, despite recurrent drought and the resultant famine. Irrigation development has not been widely practiced on large-scale bases in Ethiopia. There are few hydropower generation schemes on limited number of potential rivers. Urban and rural water-supply schemes are inadequate. In order to tackle these and other related problems, previous and current government policies have been prioritizing water and agricultural resources development.

If certain developmental schemes are to be designed and properly implemented in these fields, research-aided improvement should be put into effect. Such researches should build on the experiences of existing projects and continue until satisfactory sustainability is attained. This project (research) has therefore been intended to partly address some of water and land resources management issues by incorporating multi-disciplinary studies like geology, hydrology, hydrogeology, hydrochemistry, agronomy and Remote Sensing-Geographic Information System (RS-GIS) in order to assist in laying the foundation for developmental research works.

The project area is located within the Awash river basin. The basin is bounded to the west, south east and south by Blue Nile, Rift Lakes and Wabi Shebele basins respectively. The total catchment area of the basin is about 115,523 square kilometers and is divided into a number of sub-catchments (see Figure 1.1). The following are major sub-divisions of the Awash basin:

Upper Basin: comprises the headwaters of Awash river (west of Addis Ababa) down to Koka reservoir/dam. It forms about 10% of the total basin.

Western sub-catchments: essentially incorporate the highlands of Shoa (east of Sendafa area) up to Wello (Woldia area), and parts of the rift valley. Important left bank tributaries like Kessem, Kebena, Awadi, Negeso-Arso, Ataye, Borkena-Jara, Mile, Choleka-Telalak, Logia rise from these north-western highlands and drain towards the Awash valley.

Eastern Catchment: extends from the eastern highlands of Hararghe, stepping down through a series of piedmonts to a vast plain. With area of some 44,500 km^2, it is about 40% of the total Awash basin area. The surface runoffs (Mulu, Doba, Adu, Harewa, Erer streams) generated in this catchment does not have direct surface access to the mainstream Awash, forming effectively a closed sub-basin. Ayisha sub-basin is a small relatively dry basin located to the far east of Awash basin, adjacent to Eastern Catchment.

Upper Valley: part of the valley between Koka dam and Metahara.

Middle Valley: part of the valley between Metahara area (Awash Falls) and Adaitu.

Lower Valley: part of the valley between Adaitu and Tendaho

Lower Plains: the area downstream of Tendaho up to the farthest lake called Abhe.

The right bank tributaries Keleta, Wereso, Arba 1 (Arba Dima) and Arba 2 (Awash Arba) draining the eastern Highlands of Arsi between Chilalo Mt. and Asebe Tafari area, join mainstream Awash in the valley.

As far as accessibility is concerned, three main tarmac highways (Addis Ababa-Djibouti, Addis Ababa-Dire Dawa and Addis Ababa-Woldia), together with numerous branching all- and dry-weather feeder roads, make the basin reachable for road transport. The Addis Ababa-Djibouti railway is also another important transportation alternative. In addition, Ethiopian Airlines flies to a few destinations situated within the basin.

The specific project area for the study of surface-water groundwater interactions is the Awash valley along the course of the Awash river between Koka and Tendaho (i.e. upper, middle and lower valleys). This part of the Basin has significant surface water and groundwater resources that include the Awash river with its several tributaries, lakes, reservoirs, swamps, springs, and shallow-, deep- and thermal-groundwater. Moreover, the Awash valley has been recognized as a relatively more-developed part of Ethiopia in terms of irrigated agriculture.

In terms of research, the Awash River catchment has been of major interest for many governmental, academic and private researchers. The geological setting that include major geologic processes and stratigraphy for various volcanic, sedimentary and metamorphic successions have been suggested by researchers with reference to the Geologic Time Scale. Since substantial part of the basin is within the East African Rift System, the tectonic background of the area has been fairly investigated. In particular, the Afar Triangle with its tensional systems, comprising Red Sea, Gulf of Aden and Ethiopian Rift Valley, has been of particular interest to many local and foreign researchers.

Moreover, following the need of the Awash river basin development, land and water resources of the area have been studied, mainly considering power generation and irrigation potential. Such studies also incorporated crop potential as well as socio–economic, management, engineering and environmental components. Mentionable comprehensive studies are “Survey of the Awash River Basin” by Sogreah (1965) and “Master Plan for the Development of the Surface Water Resources in the Awash Basin” by Halcrow (1989). Although not as broad as these two, many other intensive studies on power and energy, vegetation, soil, land use, irrigation, seismicity, geology, geomorphology, hydrology, hydrogeology, hydrochemistry, engineering and environmental issues were also conducted.

Whereas quite a number of studies have been conducted in the Awash River Basin, reviewing and skimming through some of the available research works reveals that many are either very broad or project-specific feasibility studies. In addition, in the context of water resources development, many of the works were conducted mainly on the surface water resources of the Awash river and its tributaries. Few studies on groundwater resource were undertaken in specific areas within the Basin but with limited available data. To certain extent, some project studies have not only suggested particular uses for the resources but have also given designs for a number of construction schemes. Nevertheless, certain prevailing conditions within the project area of the Basin noticeably suggest the need for detailed and systematic assessments of the various aspects influencing the development of the basin, especially with regards to water resources technology.

There exist substantial surface water–groundwater interactions in the study area, where sources and amount of water flowing through the systems are controlled and influenced by a number of factors and processes. If such interactions are quantified, reliable estimates of the system’s water budget can be accounted for and the amount of water available for consumption or other purposes can be evaluated.

While this is true, for years the surface water of the valley have been utilized for irrigation, hydro-power and domestic purposes, among others. Such human activities affect the amount, rate and pattern of water flow in the systems. Apart from natural factors, it is these human activities that make the interactions of surface water and groundwater to be more spatially diverse. Understanding the water budgets of the systems and how they can change in response to human activities should be considered as an important input for water resource development undertakings.

Some measure of attention need to be given to regional groundwater resource assessment in relation to recharge and interaction studies. It is generally known that owing to quite a number of natural and anthropogenic factors, the occurrence of groundwater has a great deal of variability in space and time. Notably, the lithology and structures, and depth to water table of the riverine terrain of the Awash valley has to be assessed. In addition, there has been neither systematic nor satisfactory groundwater quality monitoring within the project area. Yet, some assessments show water quality problems, mainly with respect to salinity and fluoride concentrations.

On the other hand, the proposed part of the Basin comprises considerable irrigated farmlands as well as potential irrigable areas. For a few decades, medium- to large-scale surface irrigation systems have been in practice mainly within the valley where the river Awash plays a major role. The irrigated farms cover a total area of about 70,000ha and are owned by the state and private investors.

Such medium- to large-scale irrigation schemes may however develop drainage problems (rising groundwater levels) and irrigation-induced salinity as result of excessive and long-term irrigation. Such problems could hinder sustained productivity through actions of decreased crop yields and degraded lands with eventual abandonment of farmlands. Moreover, irrigation-induced salinity has the potential to degrade areas far beyond the agricultural sites. In connection with these, questions of agricultural water quality should be raised. Furthermore, ground-water and surface-water chemistry should not be dealt with separately, as surface and subsurface flow systems obviously interact. Accordingly, the assessment of spatial and temporal hydro-chemical variations of the systems would be part of such interaction-understanding.

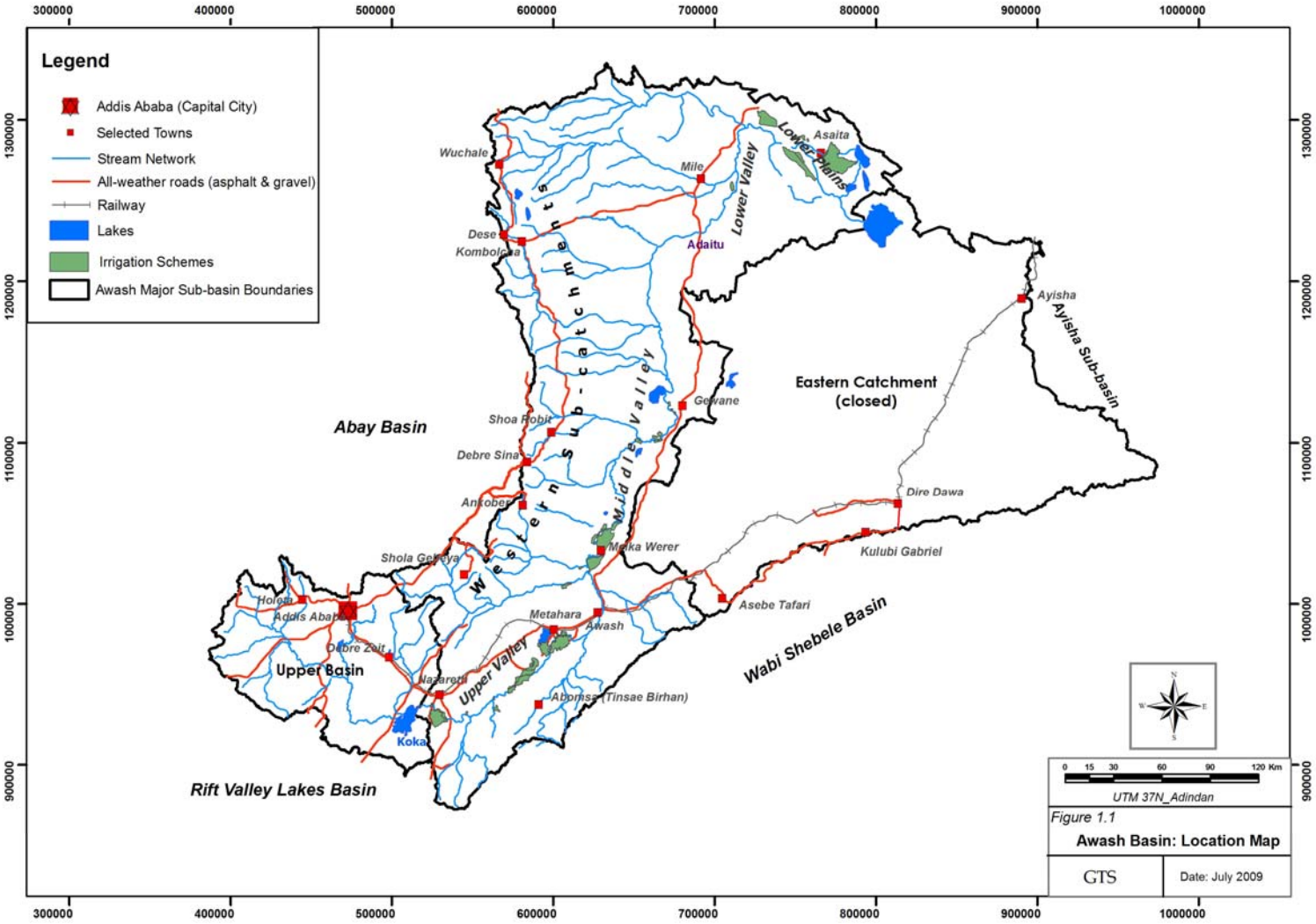
Studying such groundwater-surface water interactions to some extent requires an overview of regional recharge and discharge areas of the basin by inferring to probable regional to local groundwater flow directions. Consequently, possible flow directions of solutes which would have a direct contribution for water quality studies within the Basin could be

determined. It should assist in proper water resource potential assessment by acquiring reliable estimates of the hydrologic transfer between groundwater and surface water.

Therefore, what current conditions suggest is that there is a need for systematic and thorough assessment of the surface water-groundwater interactions and the impacts of irrigation activities on water and soil resources. Such assessments should incorporate evaluations of irrigation practices as well as effects of irrigation activities on the hydrogeological system as a whole. Furthermore, favorable conditions for surface water - groundwater resources availability have to be properly investigated, if the basin's water and soil resources are to be wisely managed i.e. utilized and protected. These studies, backed-up with adequate data, should help recommend on proper water resources utilization and also provide possible remedial measures in the context of water and land resources sustainability. This way scientific research would be a key input for integrated river basin planning and related water and agricultural resources development activities. The research or project will attempt to elaborately and effectively deal with these issues.

Generally, the research or project is intended to make a contribution to the benefit of the country for sectors involved in the fields of water resources and agricultural development and research. In line with this, the research is expected to address various issues affecting such developments within the Awash valley.

Understanding the surface water - groundwater interaction and the impacts of irrigation on the environment in general helps to assess, plan and properly manage the available resources, which can be considered as key input for integrated river basin planning and related water and agricultural resources developmental activities. Consequently, the policy makers as well as the land and water use planners would benefit as the research findings and recommendations could be crucial to designing, evaluating and properly implementing certain important schemes (projects) within the Awash Basin. Furthermore, other various governmental and non-governmental organizations as well as individuals and business entities engaged in urban and rural water supplies, irrigation development, environmental issues, research, etc would benefit from the results of the research work. Proper water and agricultural resources management, as any other proper resource development, results in the betterment of socio-economic conditions.


Legend
Addis Ababa (Capital City)
Selected Towns
Stream Network
All-weather roads (asphalt & gravel)
Railway
Lakes
Irrigation Schemes
Awash Major Sub-basin Boundaries
300000
400000
500000
600000
700000
800000
900000
1000000
1300000
1200000
1100000
1000000
900000
Wuchale
Mile
Asaita
Lower Plains
Lower Valley
Dese
Kombolcha
Adaitu
Ayisha
Ayisha Sub-basin
Eastern Catchment
(closed)
Gewane
Shoa Robit
Debre Sina
Ankober
Abay Basin
Western Sub-catchments
Middle Valley
Dire Dawa
Kulubi Gabriel
Shola Gereya
Melka Werer
Holeta
Addis Ababa
Debre Zeit
Upper Basin
Metahara
Awash
Asebe Tafari
Wabi Shebele Basin
Nazareth
Upper Valley
Abomsa (Tinsae Birhan)
Koka
Rift Valley Lakes Basin
N
W
E
S
0 15 30 60 90 120 Km
UTM 37N_Adindan
Figure 1.1
Awash Basin: Location Map
GTS
Date: July 2009

1.2 Objectives of the Study

The broad objectives of the study are:

- Assessing/evaluating surface water - groundwater interactions in the Awash valley
- Investigating effects of irrigation activities on water and soil resources
- Providing recommendations on sustainable water utilization and proposing proper soil and water management measures

Within these broad objectives, some of the specific objectives that need to be met include:

- Assessment of the natural processes or factors influencing/controlling surface water-groundwater interactions
- Investigation of the effects of human activities (reservoir dams and irrigation projects) on available surface water resources in the valley
- Appraisal of medium- to large-scale irrigated farms general performance
- Investigation of rising groundwater problems due to irrigation in selected farms, particularly where the necessary piezometer data are available
- Evaluation of Awash river water quality for irrigation
- Investigation of the extent and distribution of irrigation-induced salinity and sodicity in selected farms
- Understanding the influence of irrigation on the hydrogeological system as a whole
- Making comments on sustainable irrigation practices
- Recommending proper water and soil resources management measures and monitoring techniques at catchment- to farm-scale

1.3 Study Approach and Methodology

In order to effectively and systematically accomplish the above objectives, the following approaches and methodologies have been adopted:

- Literature review & collection of relevant materials/data that include available published and unpublished works (topographic maps, geological maps, hydro-geological maps, soil maps, land use-land cover maps, satellite images, aerial photos, etc. as well as geological, geomorphological, meteorological, hydrological, hydrogeological, agronomical data); Preparation of relevant base maps for field use
- Field works that include:
    - Reconnaissance survey of physical settings of the basin mainly along major highways
    - Collecting hydrologic, hydrogeologic, crop and other relevant data from the concerned institutions within the basin
    - Visiting water level and discharge measurement sites of the Awash river and its tributaries as well as irrigation diversions at selected points
    - Visiting the various medium- to large-scale farms in the Awash valley
    - Conducting relevant water and soil pysico-chemical in-situ tests and careful sampling
- Laboratory analyses of water and soil samples

- Creation of database, followed by data processing that incorporates analysis and interpretation of existing, field and laboratory data by using appropriate image processing, GIS, hydrological, hydrogeological, hydro-chemical and other application software

The present study has benefited from a number of field visits made across the Awash basin. Some of these visits were made principally as part of Awash River Basin Flood Control and Watershed Management Study Project (ARBFCWMSP) in which the researcher was working with team of professionals from Halcrow, Metaferia Consulting Engineers and Sogreah consulting firms. In the said project and related field works, valuable data pertinent to this study were collected independently.

1.4 Structure of the Thesis

The structure of the thesis is related to levels or scales of assessments (evaluations). The main study topics and components are accordingly summarized as follows:

Regional assessment of the Awash basin

- Geologic and geomorphic settings
- Agro-ecological setting
- Existing land cover-land use, including major irrigation schemes

Preliminary evaluation of the available water resources (mainly in the Awash valley)

- Climatic factors regionally affecting surface runoff and potential recharge
- Flow characteristics of the Awash river and its major tributaries
- Irrigation abstractions by medium- and large-scale schemes
- The Awash river reach-scale water budget
- Hydrogeological significance of the Awash riverine terrain for surface-water groundwater interaction studies

Semi-detailed assessments of effects of surface irrigation activities on water and soil resources

- Selection of farms with irrigation-induced problems and the necessary data; Amibara Irrigation Schemes (AIS) selected
- Surface irrigation and water management, incorporating crop water requirements, irrigation requirement & scheduling, irrigation abstractions and irrigation efficiency
- Groundwater table or level rise
- Irrigation water quality
- Groundwater chemistry, salinity in particular
- Soil salinity and sodocity

Conclusion and Recommendation

- Executive summary with some comments and recommendations

CHAPTER TWO

GENERAL SETTINGS OF THE AWASH BASIN

2.1 Introduction

Assessing and evaluating surface water and groundwater as a single resource and their interactions in a large river valley involves challenging tasks that require systematic and organized approaches. A sound understanding of regional climate, geology, landform, hydrology and hydrogeology is often required to understand the interactions. Furthermore, a great emphasis should also be given on the human influences to effectively deal with such interaction study.

2.2 Geologic and Geomorphic Settings

The present section is specifically designed to regionally address geologic and geomorphic settings of the Awash basin. Accordingly, the main physiographic components identified and stratigrahic units described here will effectively be used in proceeding sections to discuss various study topics and components with respect to the objectives of this research.

2.2.1 Regional Setting

The combined action of various tectonic, volcanic, and geomorphic processes have resulted in complex landmass of Ethiopia. The classic geological and geomorphic changes through geologic time-scale include tectonic and volcanic processes in the Precambrian Era that formed huge mountains followed by intense denudation-peneplanation during the Paleozoic Era. Later, slow sinking and progressive rising of part of the present East African Landmass resulted in transgression and regression of the sea respectively, forming Mesozoic sediments.

The prominent physiographic features in Ethiopia, however, have mainly been brought about by geologic and geomorphic processes of the Cenozoic Era, which are still active. Following uplift of Afro-Arabia, extensive flood basalt volcanism occurred which formed plateaus. Subsequently, East African Rift System was formed, which incorporated relatively older Red Sea and Gulf of Aden Rift Systems to form Afar depression (Tadiwos, 1995 and references therein). Main Ethiopian Rift (MER) is the northern branch of the continental East African Rift System that stretches from south Ethiopia to Afar area. Post-rifting volcanism and tectonism mainly continued on the rift floors while lacustrine, fluvial, piedmont, aeolian and other sediments deposited along margins and axes of the Rifts.

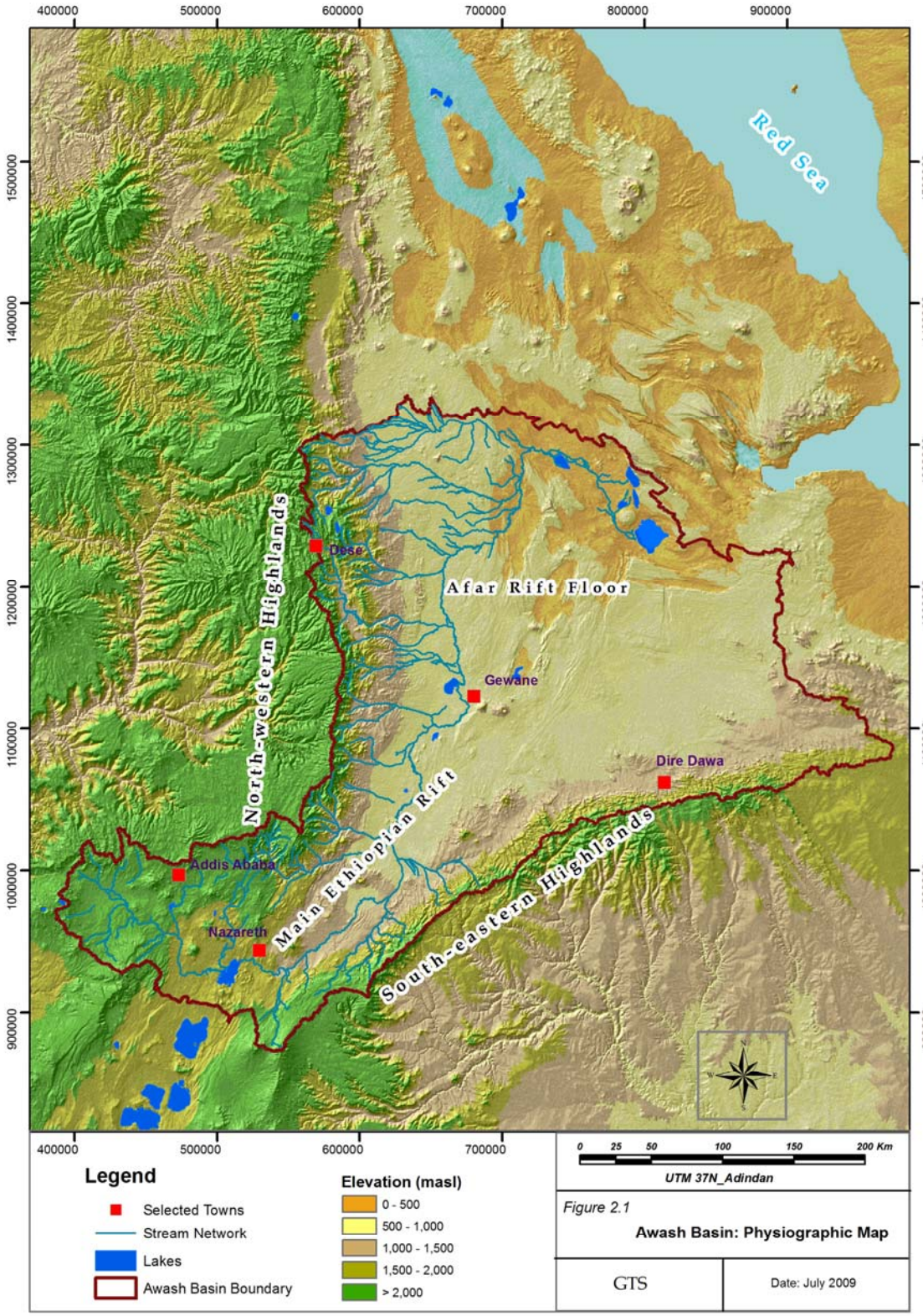
In the Awash Basin and its immediate vicinity, Main Ethiopian Rift (MER) and Afar depression, separate the north-western plateau from the south-eastern plateau, where wide escarpments have formed along their well-defined to rough margins (Figure 2.1). The nearly N-S trending western Afar structures merge with the N-S to NNE-SSW and NE-SW structures of northern and central MER to form the northwestern escarpment while the approximately E-W trending border structures of Afar and the NE-SW to NNE-SSW trending structures between Asebe Tafari area and Lake Langano mainly outline the southeastern escarpment (Kronberg, et al.,1975; Christiansen, et al., 1975; Boccaletti, et al., 1992, 1998; Tesfaye et al., 2004).

The northern MER-southern Afar transition region, the area north of Fentale volcano, is considered as an important physiographic and structural transition. Interestingly, the physiographic transition at about the latitude of junction is concurrent to the rift embayment in which Addis Ababa is situated (Tadiwos et al., 1998; Tadiwos and Hart, 1999). This feature is presumed to have been related to the ESE-WNW cross rift structure, E-W structures of southern Afar marginal graben and the Addis Ababa-Ambo Lineament, the latter possibly reflecting the regional influence of the Gulf of Aden (Tadiwos, 1995; Kazmin et al.,1980).

Wonji Fault Belt (WFB) is a wide belt of intense faulting and volcanism, considered as the active extensional axis of the MER. The several segments comprising this recent belt are arranged en echelon and are built-up of several fault swarms (showing normal type of displacements in many places), volcanic centers, flows and cones. They run mainly along the eastern part in central MER and further proceed by being relatively closer to the western escarpment in Afar depression to be bounded apparently by the NW-SW trending Tendaho rift and other faults of central Afar (Tadiwos et al., 1998; Tadiwos, 1995; Abbate et al., 1995; Mohr and Wood, 1976; Christiansen, et al., 1975; Meyer et al., 1975; Kronberg, et al., 1975).

The Afar and MER rift floor fractures and fault systems, predominantly follow the structural trend of the Red Sea System (NNW-SSE to NW-SE) and the orientation of the East African Rift System / MER (NNE-SSW to NE-SW), while still others tend to be parallel to the Gulf of Aden trend (WNW-ESE/ WSW-ENE to E-W) (Mohr, 1972; Kronberg, et al.,1975; Mezmure Haile Meskle, 1983; Abbate et al., 1995; Boccaletti, et al.,1998).

To generalize, the main physiographic units (components) of the Awash basin are the north-western and south-eastern highlands (plateaus & escarpments) and the rift valley (MER and Afar depression). Another important feature is the Addis Ababa rift embayment and part of central-western highlands that forms part of upper Awash basin.


400000
500000
600000
700000
800000
900000
1500000
1400000
1300000
1200000
1100000
1000000
900000
Red Sea
Dese
Afar Rift Floor
Gewane
Dire Dawa
North-western Highlands
Main Ethiopian Rift
South-eastern Highlands
Addis Ababa
Nazareth
Legend
Selected Towns
Stream Network
Lakes
Awash Basin Boundary
Elevation (masl)
0 - 500
500 - 1,000
1,000 - 1,500
1,500 - 2,000
> 2,000
0 25 50 100 150 200 Km
UTM 37N_Adindan
Figure 2.1
Awash Basin: Physiographic Map
GTS
Date: July 2009

The north-western and south-eastern highlands of the basin are mainly escarpments, high to mountainous relief hills and river gorges of major tributaries. As the wide escarpment zone steps down towards the rift, moderate relief structural and residual landforms, mainly hills and parallel ridges occur. There are also few well-known intermontane structural grabens/troughs (e.g. Borkena valley), also mentioned in Mezmure Haile Meskle, 1983. In contrast, the upper basin (part of the Addis Ababa rift embayment area and central-western highlands) include mainly slightly dissected plateaus that progressively become moderately dissected plains towards the rift when cut by faults and streams.

At the base of escarpments are the undulating piedmont side-slopes and plains that are affected by fluvial and gravitational processes. In paces are low to moderate relief hills that may have also been structurally affected. The rift floor is to some extent faulted volcanic terrain (ridges and centers), and in part flat to undulating alluvial plains.

2.2.2 Stratigraphy

A number of previous geological studies have given stratigraphic units with different mapping nomenclatures, ages, distribution and association of formations. Although description and discussion of units vary in context of their study objectives, findings and geographic limits, selected nomenclatures (common, old and recent) have been adopted here to deal with the lithology and stratigraphy of the Awash basin. Of major importance, untis are favorably described with respect to morpho-structural units or main physiographic components.

Pertinent studies reviewed to compile stratigraphy of the basin (descriptions of formations including radiometric and relative datings) include Barberi et al., 1975; Brotzu et al., 1980; Giday et al., 1992; Kazmin, 1979; Kazmin et al., 1980; Kazmin and Seifemichael, 1978; Kuntz et al., 1975; Merla et al., 1979; Mengesha et al., 1996; Mohr, 1962, 1972 &1983, Morbidelli, et al., 1975; Tadiwos, 1995; Tadiwos et al., 1998; Tadiwos and Hart, 1999; Taieb, 1976; Tiercelin et al., 1980; Varet and Gasse, 1978; and Justin-Visentin, 1974; Zanettin et al., 1978 &1980. The geology map has been extracted from 1:2,000,000 geological map of Ethiopia (EIGS - Mengesha et al., 1996); units are referenced with mapping units' codes (Figure 2.2).

Precambrian basement rocks (predominately gneisses, *Archean*) and ***Mesozoic rocks*** (limestones and sandstones; *Ja, Jh, Ju, Ka*) outcrop in limited areas of the basin, mainly on Hararghe highlands around Dire Dawa (southeastern highlands). The following are stratigraphic units comprising volcanic rocks and alluvial deposits of Cenozoic Era:

Ashange Formation (P2a)

- Thick, strongly weathered, tectonically crushed and tilted basalts intercalated with agglomerates and tuffs on the north-western highlands
- Eocene to Oligocene

Alagae Formation (PNa)

- Mainly aphyric stratoid basalts, associated with rhyolites, ignimbrites and trachytes on the north-western and south-eastern highlands
- Late Oligocene to Mid Miocene

Tarmaber-Megezez Formation (Ntb)

- Variety of basalts associated with locally occurring phonolites, trachytes, and rare rhyolites on the north-western and south-eastern highlands
- Overlie the Alajae Formation
- Arba Gugu and Anchar Basalts are included in this unit
- Mid to Late Miocene

Arba Guracha Formation (Nmr)

- Welded and unwelded tuffs and ignimbrites that comprise part of the southeastern and eastern escarpments of Afar and northern MER
- Directly overlain by the Nazret Group and pinch out to be replaced and/or overlain by the basalts of the Tarmaber –Megezez Formation
- Mid Miocene

Dalaha Formation (Ndb)

- Basalts with rare intercalations of ignimbrites and detritic deposits
- Mainly outcrops Logia area in the Awash basin
- Late Miocene

Afar Stratoid Series (Na)

- Basalts (generally porphyritic and vesicular) on the rift valley (Afar floor)
- Predominately affected by numerous faults and fissures and in places exhibit nearly perfect columnar joints
- Late Miocene to Pliocene age

Nazret Series (Nn)

- Mainly ignimbrites, rhyolites, unwelded tuffs, ash and pumice that cover part of the rift floor, margins and escarpments of MER and Afar
- Thicker in the rift, tend to thin-out on the escarpments and plateau margins; affected by faulting
- Late Miocene to Pliocene age

Gara Gumbi and Wechecha Formations (Nc)

- Gara Gumbi Formation: silicic (rhyolitic and trachytic) volcanic centers like Gara Gumbi, Asebot, Afdem, Bara At, and Gura Adi aligned along the base of the eastern and southern escarpments of the northern MER and Afar
- Wechecha Formation: predominantly trachytic volcanoes such as Wechecha, Yerer, Furi and Mengesha (a satellite of Wechecha) in the Addis Ababa region

- Named Chilalo Formation in some studies
- Late Miocene to Pliocene

Bofa Basalts (Nb)

- Rift floor basalts locally vesicular and fresh with several flows separated by palaeosols and scoriaceous horizons
- Well developed in the northern MER, the Bofa Basalts are exposed along the cuts of the Awash river and its tributaries and form a wedge between the Nazaret Group and the Dino Formation at places
- Pliocene

Bishoftu Basalts (NQtb)

- Basalts associated with numerous well preserved scoria cones that outcrop in the subdued escarpments of MER, south of Addis Ababa-Debre Zeit and near the northern MER escarpment
- Late Pliocene to Pleistocene

Dino Formation (Qd)

- Predominately ignimbrites, unwelded pyroclastics, waterlain pyroclastics occasionally intercalated with aphyric basalts and lacustrine beds
- Covers the rift floor and escarpments of MER
- Pleistocene

Quaternary Rhyolitic Volcanic Centers (Qr)

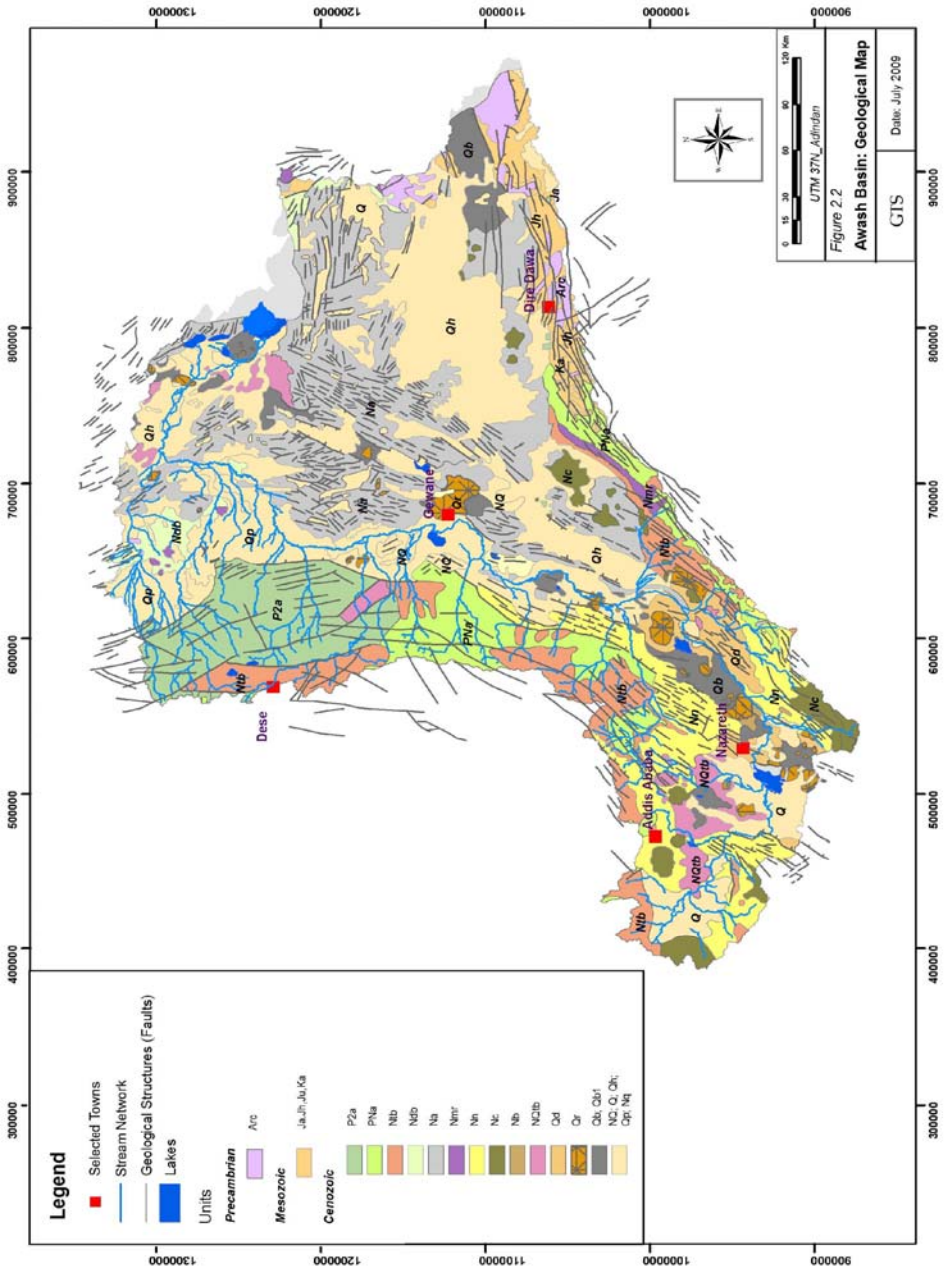
- Major silicic centers (rhyolites and trachytes) along the axial zone of MER and Afar; associated with obsidian, pumice, ignimbrite, tuff/ash and rare scoriaceous basalts
- Segments of WFB in the Awash valley host major mountains like Bosete, Kone, Fentale, Doffen and Ayelu Mountains Bosete, Kone, Fentale, Doffen and Ayelu
- Pleistocene for Bosete as reference

Quaternary Basalts (Qb & Qbt)

- Basalts (typical aa or pahoehoe), scoria cones and hyaloclastite deposits concentrated along the axial zones of WFB; partly make up the axial and marginal volcanic ranges and complexes of Afar
- Pliestocene to recent age

Pliocene to Holocene Sediments (NQ, Q, Qp, Qh)

- Continental sediments of different origin: fluvial, lacustrine, aeolian, etc. deposited mainly in the rift floor as well as in grabens on the highlands
- Includes Hadar Formation: sediments rich in well preserved vertebrates; exposed along the cuts of the Awash river and its tributaries at the base of the western escarpment of southern and central Afar
- Incorporates lacustrine sediments of Quaternary age in the MER and Afar (in the northern MER presumably deposited from large ancestral lake upon shrinkage due to Late Pleistocene tectonic movements or marked drier climate; other lacustrine deposits consist of re-deposited volcanic sands, tuffs with calcareous material and diatomite).
- Comprises wide flood plain deposits of the Awash river and its tributaries
- Includes pediment or detritic deposits, generally gravelly, mainly along the base of escarpment slopes and piedmonts
- Aeolian active sand dunes laid down on top of relict dunes in Assaita area
- Saline soils and evaporites are also known to occur in the rift



2.3 Climate

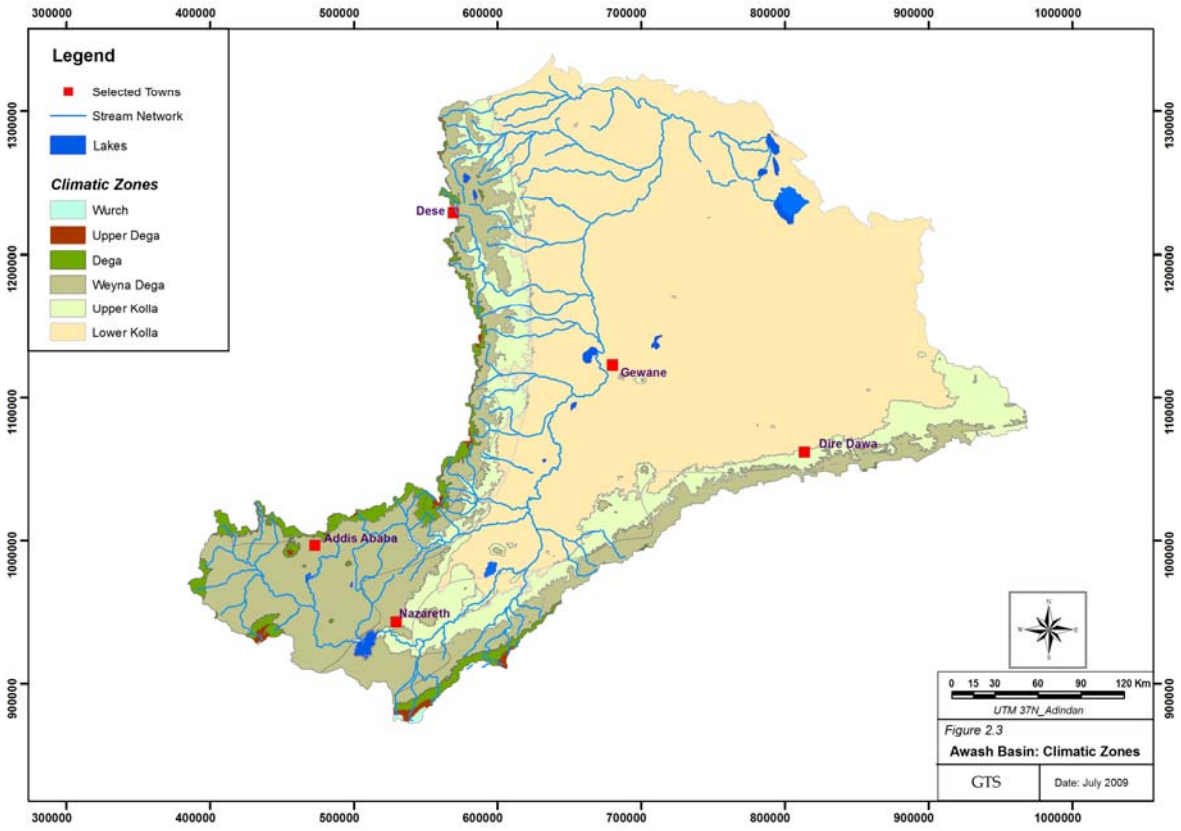
The Awash basin is characterized by wide-ranging agro-climatic zones with varied ecological conditions. With extreme ranges of topography, vegetation, rainfall, temperature and soils, the basin extends from both semi-desert lowlands to cold high mountain zones.

Figure 2.3 portrays major traditional climatic zones of the Awash Basin. Although altitude has been the major determinant for this traditional Ethiopian classification, it can be refined more with temperature and rainfall. Its use on a regional scale has been found very valuable.

Rainfall and evapotranspiration have been treated separately in next chapter; these parameters are also shown to vary with altitude. Therefore, it has been relevant to describe the climatic zones with respect to main physiographic components. Given these zones with likely defining natural factors, the type of agriculture practiced as well as the type of vegetation will essentially vary.

The north-western and south-eastern highlands (plateau and escarpment) including the upper basin are dominantly Woina Dega and partly Dega. Settled rainfed agriculture is practiced with possible double cropping in areas receiving considerable *belg* rainfall (March-April) in addition to *Kiremt* rainfall (main rainy period, June-August).

On the other hand, the rift valley is semi-arid (Lower Kolla to Bereha), except restricted portion of the upper valley. It requires irrigation as rainfall is not sufficient to meet water requirements of most crops. The favorable topography and availability of the Awash river water has encouraged irrigation development.



2.4 Land Use - Land Cover

A generalized land use - land cover map of the Awash basin and its immediate environs is presented in Figure 2.4. The data used has been prepared by Woody Biomass Inventory and Strategic Planning Project (WBISPP) that came-up with more than 50 sub-classes. Simplified to less than10 main classes, the map is in agreement with the broad climatic (agro-ecological zones) and physiographic components of the basin described earlier.

Cultivated lands are mainly croplands under rainfed or irrigation. Rainfed agriculture is the most commonly practiced traditional farming system in Ethiopia. Generally, the area below 1500m is considered as rough lower limit for the highlands and rainfed-agriculture. As a result, most of the upper basin, north-western and south-eastern highlands including some parts of the upper valley are intensively cultivated. The main crops grown under rainfed agriculture include crops like teff, barely, wheat, beans, maize, lentils, etc. Apart from rain-fed agriculture, the Awash Basin is known for its irrigated agriculture. A number of medium- and large-scale irrigation schemes found within the Awash valley has been separately discussed in the next section.

The type of vegetation and their spatial variation mainly describes land cover. Major mapping units include grassland, shrubland, woodland and forests. The north-eastern and south-eastern escarpments are predominately shrublands. On the highlands, shrubs are associated with croplands. The pediment slopes along escarpment margins are mainly covered by shrubs and grasses.

Part of the rift valley has been mapped as barelands: exposed volcanic rocks and sands/soils with sparse vegetation. While still to some extent the rift is semi-desert grassland with shrubs, riparian vegetations occur along considerable stretches of mainstream Awash.

On the other hand, the Awash basin is endowed with several wetlands of various types (open water, perennial and seasonal swamps/marshes). Mentionable lakes on the north-western highlands are Hayk and Hardibe while Lakes Bishoftu, Hora, Beseka, Le Ado, Hertale, Yardi, Gemeri, Adobed, Afambo and Abe are some of the rift lakes in the basin. On the other hand, artificial lakes like Koka and Aba Samuel are reservoirs primarily constructed for hydro-power generation whereas Geffersa and Legedadi are reservoirs constructed to supply potable water to the metropolitan area of Addis Ababa after treatment.

Large perennial swamps in the basin include Gedebassa swamp bordering Yardi near Gewane, Borkena swamps within the structural graben on the north-western highlands, and lower plains swamps near the terminal lakes. Other permanent swamps and seasonal

marshy areas are also found in the vicinity of other lakes and where topography permits their existence, predominately within structural basins.

Major urban centers of mappeable scale include the capital city of Ethiopia, Addis Ababa, and Dire Dawa. Nonetheless, Holeta, Shewa Robit, Debre Sina, Ankober, Dese, Kombolcha, Debre Zeit, Mojo, Nazareth, Metahara, Awash, Gewane, Semera, Tinsae Birhan (Abomsa), Asebe Teferi and Meiso, are important towns of the basin amongst many. Having relatively significant populations, most of these towns are located on the highlands, while others in the valley are mainly found along the major state farms, rail road, and highways.

2.4.1 Irrigation Schemes

Table 2.1 lists existing medium- and large-scale irrigation schemes in the Awash valley with their respective gross command area, principal crops grown and type of supply system (diversion weir gravity or pump supplied). Most of the schemes are located along mainstream Awash while few others are located along major tributaries like Keleta, Wererso, Kessem, Kebena and Mile. At present, most of the schemes are state-owned while still considerable schemes are controlled or run by private investors or by farmers' associations (cooperatives).

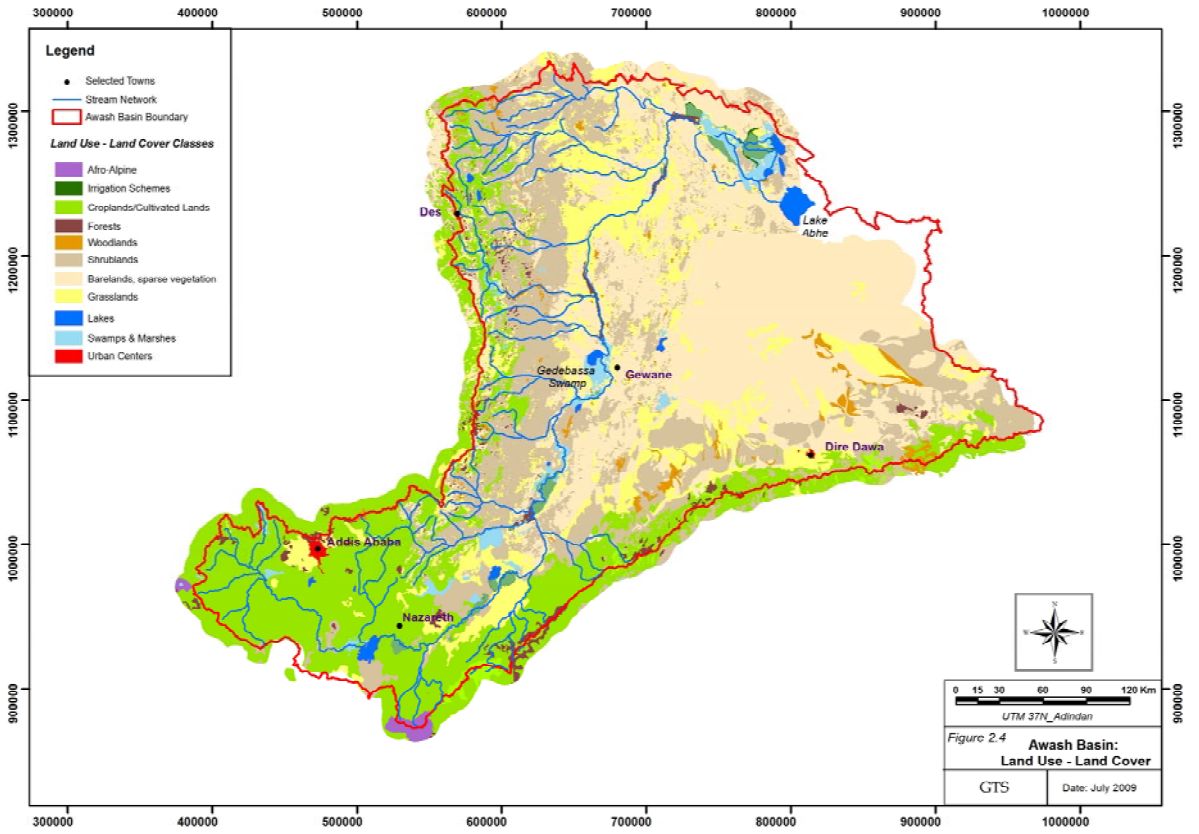


Table 2.1 Medium- and Large-Scale Irrigation Schemes in the Awash Valley

Location	Farms	Gross Area (ha)	Remark
Upper Valley	Wonji/Shoa Sugar Estate	6,000	Sugarcane plantation with two factories; pump supplied; Future expansion include Dodota and Welenchiti areas
	Wonji Out-growers (Kuriftu, Boku, Adulala, Wake Mea, Wake Tio, Bishola, Hargeti)	1,100	Sugarcane plots run by farmers' associations/ cooperatives
	Upper Valley Agro Complex and other farms (Degaga, Tibila, Merti Jeju, Nura Hera & others)	9,000	Horticulture (fruits & vegetables) and cotton; Merti Jeju farms located on the right bank of Awash while Nura Hera farms on the left bank; diversion weirs and pump stations
	Metahara Sugar Estate (Abadir & Merti)	10,000	Sugarcane plantation with a factory; limited orchard area (citus fruit); diversion weirs; Future expansion areas include over 3,000ha in the immediate vicinity
Middle Valley	Kesem-Kebena Schemes (Awara Melka and Yalo)	1,900	Over 10,000ha additional area envisaged for irrigation development after completion of Kesem dam
	Amibara Irrigation Schemes (Melka Sadi, Former Melka Sadi Banana, Melka Werer, Former Amibara Settlement, Werer Research Center, Ambash, Algeta & Sublale farms)	15,000	Right bank schemes in Amibara area; Mainly gravity supplied, about 10,000ha (Melka Sadi diversion wier), while others are pump schemes; main crop grown is cotton; Sublale farm (about 600ha) is considered as part of Angelele farms in other studies
	Dofen Bolhamo-Gidaro	1,700	Left bank farms in Amibara area, abandoned for years; Considered in the future planned development areas of Kesem dam project
	Angelele and Haledebi	1,200	Except Asoba area (covered by cotton), the rest abandoned
	Gewane Area Complexes including Bure Modaytu area (Kuda, Debel, Gewane, Ras Adas, Inta Adoyta, Ayroli, Gel Ela Dora & Others)	2,700	Considerable portions of the farms have been abondoned; very recently some farmers re-engaged in limited areas; Future plans include expansion and reinstatement of farm areas
Lower Valley	Mile Farms	1,000	Abandoned farms; very recently limited area covered by crops
Lower Plains	Dubti, Dit Bahri, Tangay Kuma, Senbeleta, Awsa Assaita & others	25,000	Cotton growing farms; Considerable area abandoned; Future expansion planned in the area include additional area of over 30,000ha, mainly for sugarcane plantation, after completion of Tendaho dam

It may be important to note that quite a number of state farms in the middle valley and the lower plains have been handed-over to Afar State or local Afar people as compensation in the 90s. As a result, substantial portions of some farms have been abandoned, owned by private investors (mostly leased from the Afars), or controlled by farmers' cooperatives organized by Weredas of Regional States.

Apart from existing irrigation schemes, a number of potential irrigation development areas have been proposed or studied (Sogreah, 1965; Halcrow, 1989; Booker Tate-MCE, 2003; WWDSE-WPCS, 2005; Booker Tate et al., 2005). Some of the proposed schemes are currently under construction or at feasibility study level. For example, Kesem and Tendaho dams are under construction, which are planned to develop large irrigation command areas in the middle valley and the lower plains. Feasibility studies on expansion of Wonji/Shoa and Metahara sugar plantations in the vast plains of the upper and middle valleys have been finalized. Other potential areas identified include Becho plain in the upper basin, and Fentale area, Alaydege plain and Gedebassa swamp areas in the upper and middle valleys.

CHAPTER 3

GENERAL HYDROLOGY AND HYDROGEOLOGY

3.1 Introduction

The natural components or processes that take-up leading roles within the hydrologic cycle are precipitation, evapotranspiration, surface water and ground water. This chapter at the start deals with the temporal and spatial variations of the climatic conditions that potentially affect runoff processes and stream flow characteristics in the Awash basin. Rainfall and evapotranspiration are considered as important hydro-meteorological parameters.

Subsequently, hydrologic descriptions of the Awash river has been forwarded by dividing the mainstream into reaches. Since the area of interest in this study is the Awash valley, discussions are forwarded for mainstream Awash downstream of Koka dam. Catchments contributing runoff to the mainstream Awash in these reaches are also treated herewith.

Having done all these, water balance of the Awash river has been performed by considering the recent level of irrigation development. Effort has been exerted to link results with previously discussed natural factors and existing anthropogenic (human) influences on the surface and groundwater resources.

3.2 Hydro-meteorological Data Analysis

Meteorological data were made available primarily from the National Meteorological Services Agency (NMSA). As complementary, few data were also gathered from agricultural research institutes, large scale farms and from archives of FAO/CropWat (CLIMWAT files), and other pertinent previous studies. For more than 100 stations, daily rainfall data have been acquired. With regards to the other climatic parameters (temperature, wind speed, sunshine duration, relative humidity, etc), monthly data have been obtained for several stations.

3.21 Rainfall

Figure 3.1 shows the spatial variation in rainfall amount in the Awash basin. Mean annual rainfall calculated for more than 140 point stations located within and around the basin have been used to create the raster surface employing preferred GIS interpolation technique. It has been purposefully reclassified at variable intervals to spatially show rainfall variations with respect to major physiographic units. Interestingly, the isohyets selected align parallel to the general rift structures, indicating that rainfall is strongly controlled by altitude.

Whereas it is important to study the spatial variations, it is also of paramount importance to also see seasonal variation of rainfall within the Awash. The annual migration of Inter Tropical Convergence Zone (ITCZ) essentially determines the seasonal rainfall distributions within the Awash basin. Noticeably, the basin mainly experiences two rainy seasons during the periods of February-May and June to September depending on the position of the zone.

The seasonal rainfall distributions and their pattern over the basin vary spatially. Monthly rainfall distributions are compared at selected stations by employing the method adopted from the precipitation data analysis of Sogreah (1965) for Awash river basin. Subsequent studies by Daniel Gamachu (1977) and Halcrow (1989) have also adopted this method to regionally describe the rainfall regimes of Ethiopia and the Awash river basin respectively.

In this study, relatively long term daily precipitation data are used to calculate the mean monthly rainfall of stations, from which the rainfall module (RM) and rainfall coefficients (RC) are calculated (see annex). In this way, the monthly mean rainfalls are represented as proportions of the 12 monthly values for each station. Therefore, the graphs would be comparable and independent of the absolute values of the monthly mean rainfalls.

Figure 3.2 portrays graphically seasonal rainfall distributions for few selected stations located in different physiographic units. Bearing in mind the intended purpose, the runoff-contributing highlands of the western catchments and the rift valley have been given more attention. For comparison, Addis Ababa located in the upper basin and Tinsae Birhan (Abomsa) on the Arsi highlands of the Arba river has been included.

The pattern presentations clearly show that the Addis Ababa area distinctly vary from the north-western highlands of the western catchments, and the rift valley area. The rainfall distribution of Addis Ababa shows a tendency to have the two rainy periods merged with June rainfall on average substantial. The pattern may not however be representative for the whole upper Awash basin but relevant for the central-western highlands of Ethiopia. In contrast, the rainfall distribution is bimodal (quasi-bimodal) type in most parts of the rift proper (the valleys and plains), and in the north-western highlands. Characteristically, small rains come about in March-April while Kiremt with quite higher concentration occur in July and August. With extremely contrasting rainy periods, the highlands of Kesem river share the same high amounts of July -August rainfall but with very limited belg rainfall.

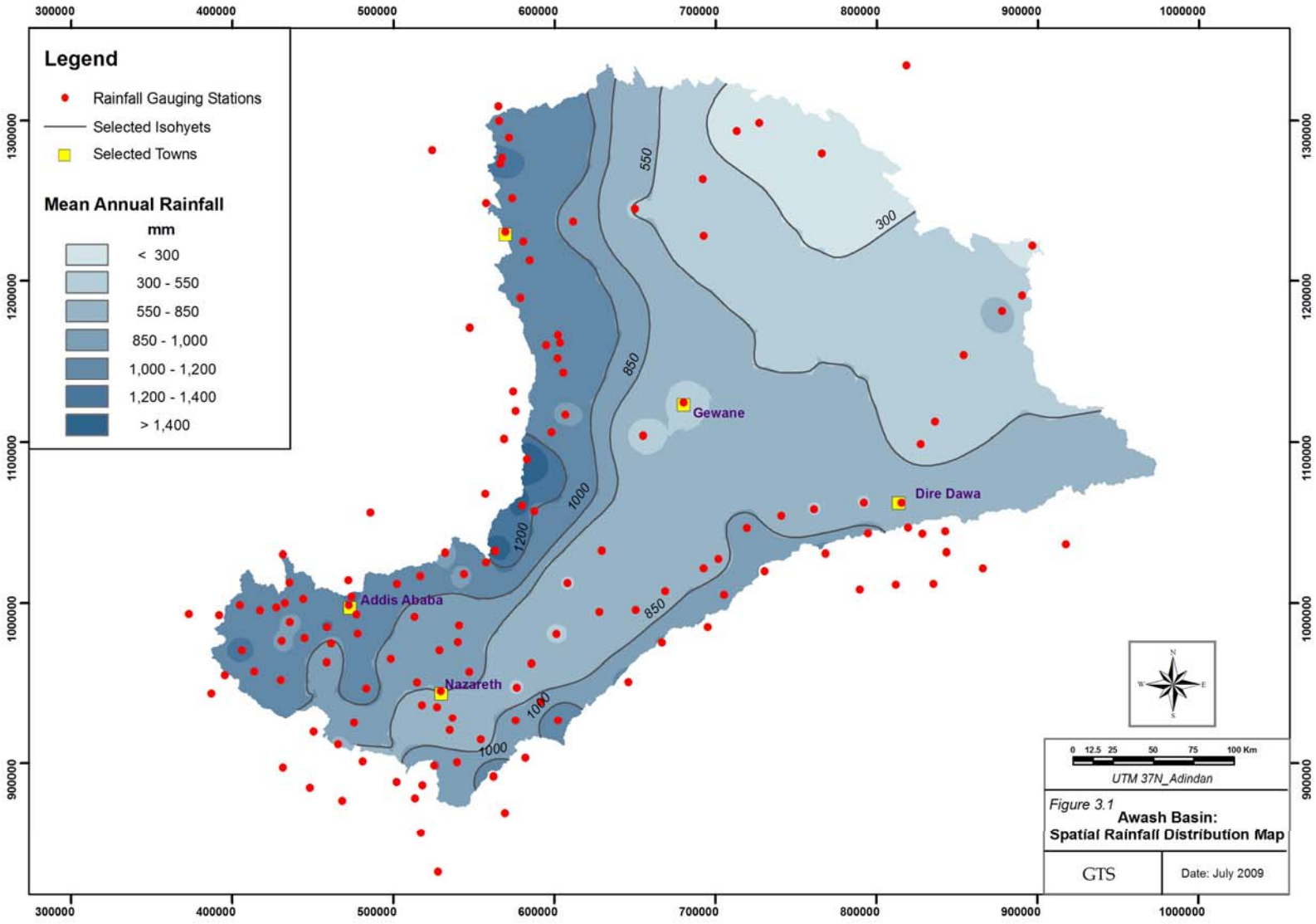
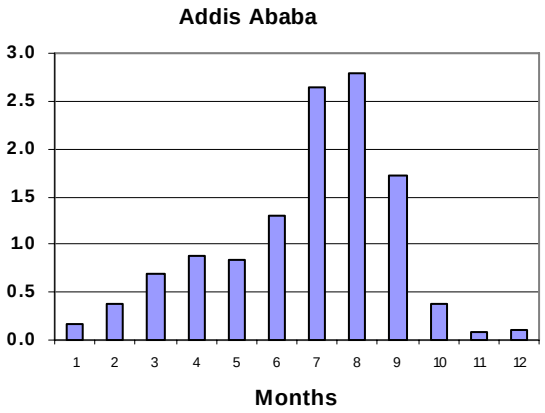
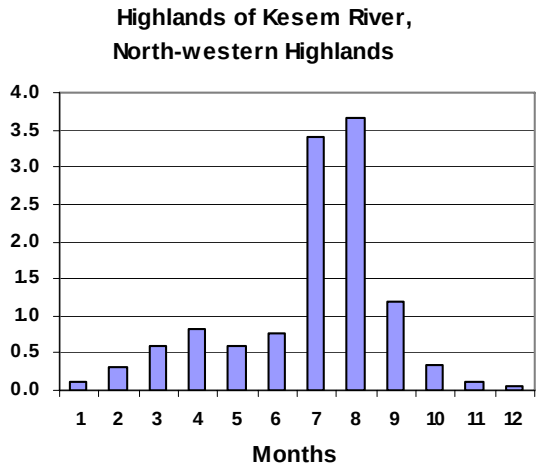
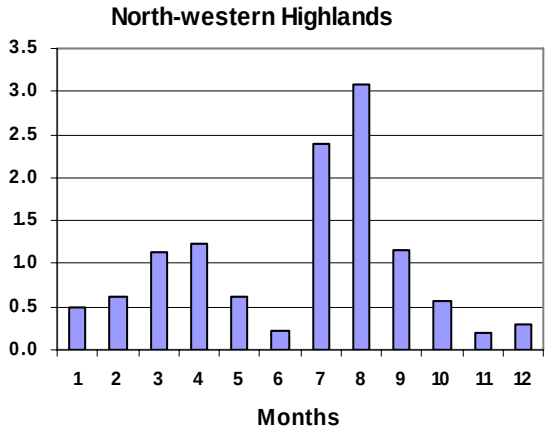
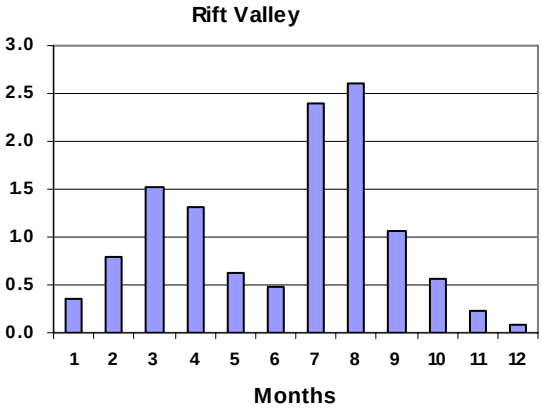

Legend
Rainfall Gauging Stations
Selected Isohyets
Selected Towns
Mean Annual Rainfall
mm
< 300
300 - 550
550 - 850
850 - 1,000
1,000 - 1,200
1,200 - 1,400
> 1,400
300000
400000
500000
600000
700000
800000
900000
1000000
1300000
1200000
1100000
1000000
900000
550
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1200
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1000
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Gewane
Dire Dawa
Addis Ababa
Nazareth
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0 12.5 25 50 75 100 Km
UTM 37N_Adindan
Figure 3.1
Awash Basin:
Spatial Rainfall Distribution Map
GTS
Date: July 2009

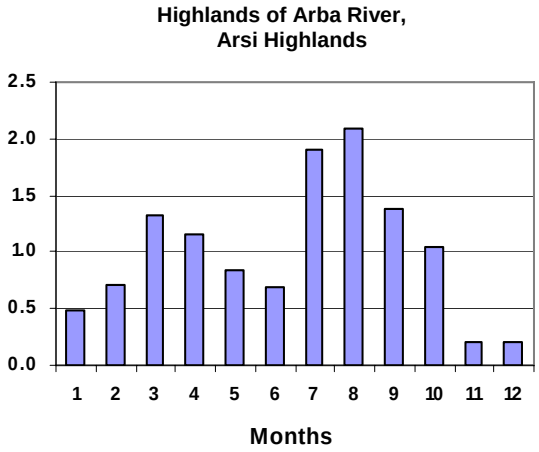
Figure 3.2 Rainfall Regimes Showing Seasonal Variations











Note: Rainfall Coefficients on the X-axis (unitless)

3.22 Potential Evapotranspiration

Potential evapotranspiration (PET) can be estimated using different techniques. The most widely used methods for estimating PET from meteorological parameters include pan evaporation, Thornthwaite, Penman and Penman-Monteith methods. Penman-Monteith method can effectively be used to estimate potential evapotranspiration provided that meteorological data such as minimum and maximum temperature, relative humidity, wind speed at 2m, sunshine duration and solar radiation are available. The FAO Penman-Monteith equation (Allen, et al., 1998) is as follows:

$$ET = \frac{0.408\, f\,(Rn - G) + g\,(900/T + 273)\,U_2\,(es - ea)}{f + g\,(1 + 0.34\,U_2)}$$

Where,

ET = potential evapotranspiration (mm day $^{-1}$)

Rn = net radiation at the crop surface (MJ m^{-2} day $^{-1}$)

G = soil heat flux density (MJ m^{-2} day $^{-1}$)

T = mean daily air temperature at 2 m height (^{0}C)

U_2 = wind speed at 2 m height (m s^{-1})

es = saturation vapour pressure (KPa)

ea = actual vapour pressure (KPa)

es – ea = saturation vapour pressure deficit (KPa)

f = slope vapour pressure curve (KPa ^{0}C^{-1})

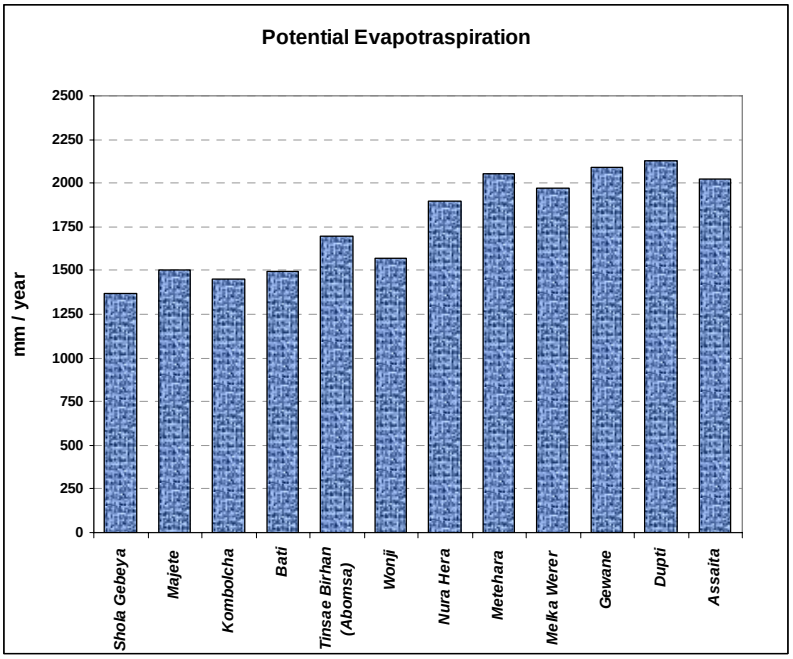
g = psychromertric constant (KPa ^{0}C^{-1})

In this study, potential evapotranspiration has been calculated using Penman-Monteith method for some selected stations on the highlands and valleys of the Awash Basin, excluding the upper basin and closed eastern catchment. Stations with necessary climatic data selected are Shola Gebeya, Majete, Kombolcha and Bati on the north-western highlands and Tinsae Birhan (Abomsa) on the eastern highlands. In the rift, typical stations from the upper valley to lower plains include Wonji, Nura Hera, Metahara, Melka Werer, Gewane, Dubti and Assaita.

As it can be seen in Figure 3.3, potential evapotranspiration is relatively higher within the rift than the highlands. PET estimated for Shoa, Wello and Arsi highlands (plateau and escarpment) range from 1300 to 1700 mm/year. In the upper valley, PET varies from 1550 to 1900 mm/year. From middle valley to lower plains (Metahara to Assaita), annual PET is between 1950 to 2150 mm/year. In general it may be deduced from this analysis alone that

PET increases with decrease in elevation. Monthly estimated values for the stations are attached in the annex.

Figure 3.3 Annual Potential Evapotranspiration at Selected Stations



In contrast to PET, actual evapotranspiration (AET) is highly dependent on availability of water. Generally, when the available soil moisture is depleted depending on seasonal climatic conditions and/or vegetation effects, the potential evapotranspiration exceeds actual evapotranspiration. On the other hand, AET will be equal to PET for permanent wetlands (open water reservoirs and permanent swamps) as water is not a limiting factor.

It may be reasonable to consider that recharge on the highlands can occur during months when rainfall exceeds PET, indicating the importance of direct recharge. In semi-arid areas of the Awash valley, PET is on average higher than precipitation. In such regional moisture-deficit conditions, indirect recharge from river flows becomes of importance.

3.3 The Awash River: Reach-scale Hydrologic Description

The Awash river rises near Ginchi town in the upper basin and terminates in a series of swamps and lakes in the lower plains. In general, the flow of the Awash river and its tributaries is into the semi-arid valleys and plains away from the Dega and Woinadega highlands. The overall channel length of the Awash is greater than 1250 km.

As stated earlier, hydrologic descriptions are primed for the Awash valley downstream of Koka dam. Depending on the determining factors, the way of discussing the hydrology (flow characteristics of the Awash river and its tributaries) varies accordingly. Principally governed by the natural factors (climate, geology, physiography), agricultural development also play important roles in influencing flow characteristics.

Daily stream flow data for important stations have been obtained from Ministry of Water Resources, hydrology department. Figures 3.4a&b presents mean monthly flow hydrographs of the mainstream Awash and major tributaries at selected gauging stations. By studying the flow patterns with respect to major physiographic units, the effects of seasonal rainfall have been inspected and discussed where necessary in proceeding descriptions. Moreover, the mean flow volumes on the graphs may give an idea of the available water resource at selected stations by providing quick estimates.

Awash River: Koka to Metahara

The Awash river immediately below Koka dam is supplied by the regulated reservoir releases and occasional spills. It flows in a narrow volcanic gorge before it gets into a relatively wide valley near Melka Hidi. Coming out, the Awash meanders across the alluvial plains of the Wonji/Shoa sugar estate and out-growers farm area before it reaches Awash Melkassa reservoir.

The dam and reservoir at Melkassa have been principally built for hydroelectric powers stations of Awash 2 and 3 (the hydropower station at Koka being Awash 1). Nevertheless due to heavy siltation, the current capacity of the reservoir has reduced to the level that it can no longer store the required amount. This condition has led to the situation that the Awash river is directly diverted for the two stations by a narrow canal, except during high flows that floods are let to pass by flap gates and a siphon. As a result, the natural channel immediately downstream runs dry for most of the dry seasons. The diverted water after generating power at the two stations joins the natural channel at about 5km downstream of the intake.

From this area, the Awash river then flows to Sodere area where it is joined by a number of thermal springs. Hot springs include Kidane Mihret, Abadir, Giyorgis, and Mariam among others. Further downstream, the Awash river receives considerable surface inflow from the right bank tributaries of Keleta and Wererso before reaching Nura Hera. These tributaries have their headwaters on the Arsi highlands (see Figure 3.5). Keleta stream is gauaged near Sire.

The Awash river flows in Nura Hera area by supplying irrigation water to left bank (Nura Hera) and right bank (Merti Jeju) farms of the Upper Awash Agro Industry and other private farms. Then it travels to Metahara area where major diversions occur for Abadir and Merti farms of Metahara Sugar Factory (MSF). It is important to note here that substantial amount of available water is abstracted in these sub-reaches.

An important lake worthy of noting here is Lake Beseka, which is located close to Metahara sugar plantation. The areal size of the lake has increased from about 3 km^2 in the mid 60's (Zenaw Tessema, 1998) to about 45 km^2 in the early 2000 (measured from available Landsat imagery).

Important stations on the main river in the upper valley are Awash below Koka dam, Awash at Wonji and Awash at Nura Hera. The station records of Nura Hera however do not extend beyond year 1997 but with more than 15 years of data it has been considered valuable for presentation. As it can be seen in Figure 3.4a, the regulated releases of the Koka dam have its effects clearly on stations of Wonji, Nura Hera and even on Metahara.

Awash River: Metahara to Gewane

Immediately downstream of the Metahara sugar estate, the mainstream Awash gets into deep volcanic gorge forming the famous "Awash Falls". Controlled by the volcanic gorge, the river flows NE to NNE upto Awash gauging station where it changes its direction to nearly N-S direction. Two major tributaries, Arba and Awash Arba, as well as few other seasonal streams join the Awash in this sub-reach from the right bank.

Between Awash and Melka Werer, the Awash river flows to be joined from the right bank by Awash Arba river which then meanders to receive the Kessem and Kebena rivers from the left bank. The intake structure just below the Melka Sedi gauging station permits irrigation diversion to the gravity supplied Amibara Irrigation Schemes. After being gauged at Melka Werer (east of Dofen Mt), the river travels into Da Itele area by supplying irrigation water to the Amibara and Asoba/Blen pump schemes. The river then flows north, past Angelele and Haledebi, joined by Awadi river from the right bank to reach Hertale area.

Below Hertale area, the river flows into the Gedebasso swamp where it anabraches. It provides pumped irrigation water to the farm complexes of Gewane area. Negeso- Arso river is important left bank tributary that flows into this river(Awash)-swamp(Gedebassa)-lake(Yardi) complex area.

Important flow gauging stations on mainstream Awash include Awash, Melka Sedi and Melka Werer (see flow hydographs, Figures 3.4a&b). Further downstream, there is an abandoned station at Hertale, near Kuda farm (just upstream of the Gedebassa swamp). As for the main tributaries, Kesem river is gauged at Awara Melka while the station on Kebena river has long been abandoned.

Awash River: Gewane to Tendaho

After Gedebassa swamp, the main river is joined by significant tributaries from the left bank (Ataye, Jara-Borkena and Choleka-Telalak) before it is gauged at Adaitu. There is considerable riparian vegetation of about 2km wide along the river upto Choleka-Telalak river confluence.

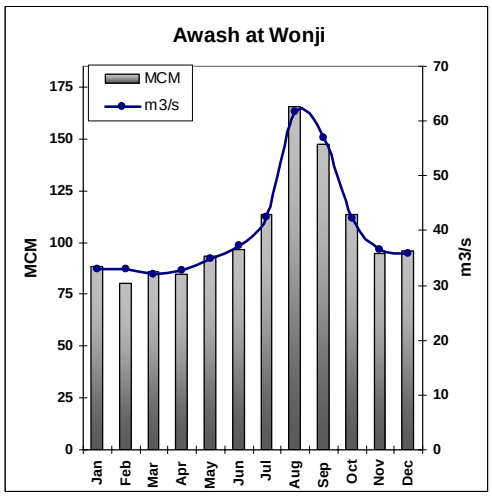
Downstream of Adaitu, the mainstream awash makes a turn to the right (east) flowing through volcanic ridges upto certain stretch and then comes out to the north to flow in the alluvial lower valley. A major left bank tributary Mile joins Awash before reaching Tendaho. Some abandoned channels of the Awash river could be observed on available Landsat satellite images.

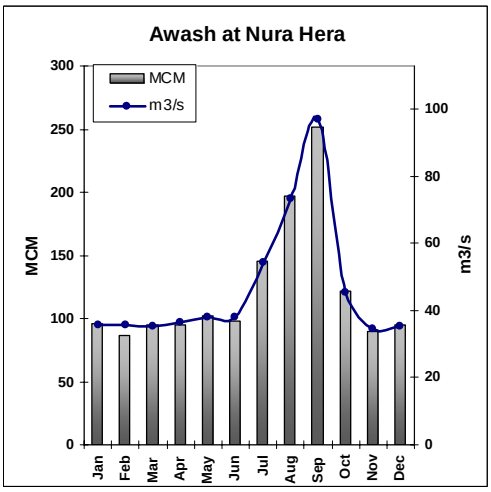
The mean monthly flows hydrographs at Adaitu and Tendaho in Figure 3.4b show natural flow pattern with bi-modal monthly mean peaks influenced by north-western highlands rainfall pattern (Figure 3.2). This indicates that Koka's regulated flow releases effect have relatively decreased downstream of Gedebassa swamp and also that there is considerable inflow from left bank tributaries.

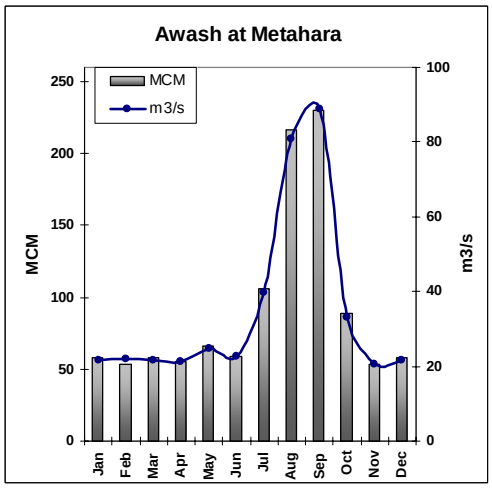
Lower Plains

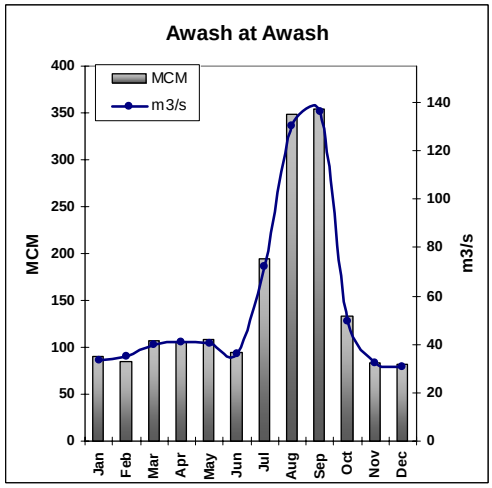
In the lower plains, i.e. downstream of Tendaho gauging station, the main river is joined from the left bank by Logia stream whose contribution during the dry seasons is minimal. Downstream of Logia confluence, the Awash river flows through chains of swamps and lakes. Before reaching Assaita, the river flows in a relatively defined channel before it splits into three main branches, namely, Berga, Bokaitu and Siblu. It finally enters into Lake Abe, the farthest of all the other lower plains lakes.

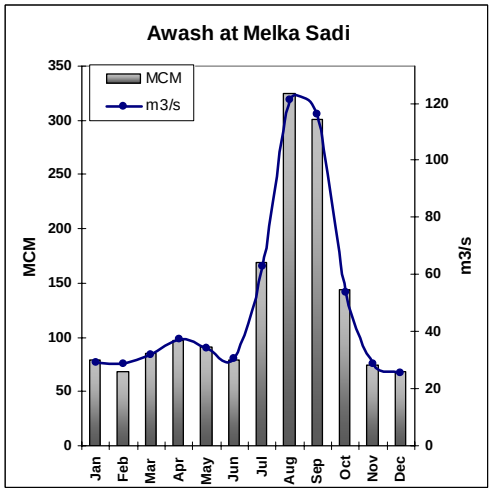
Figure 3.4a Mean Monthly Stream Flow Hydrographs at Selected Stations











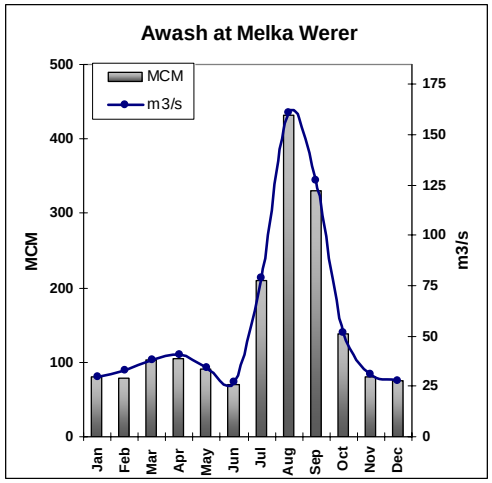
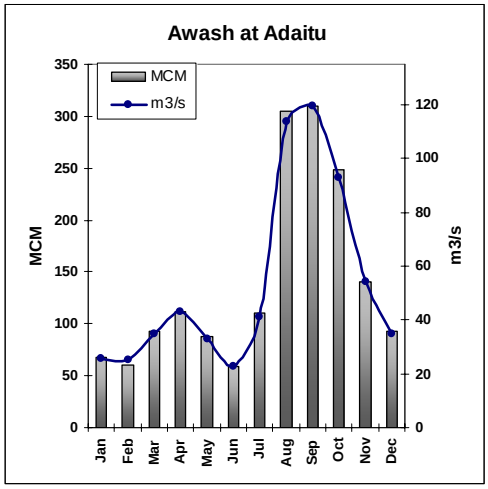
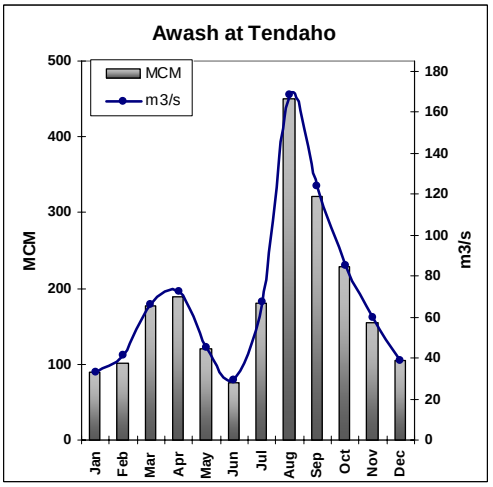
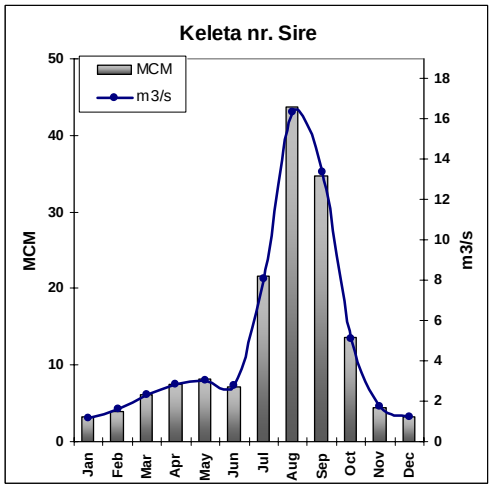
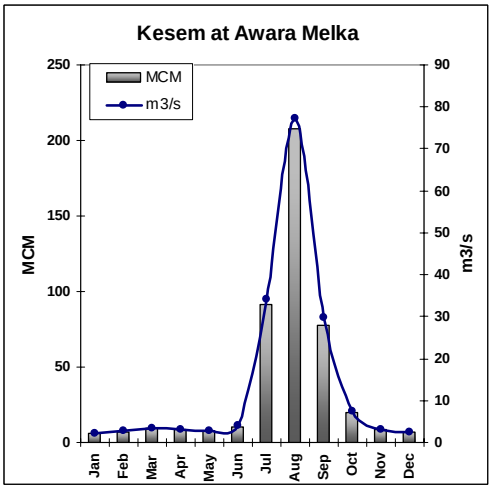


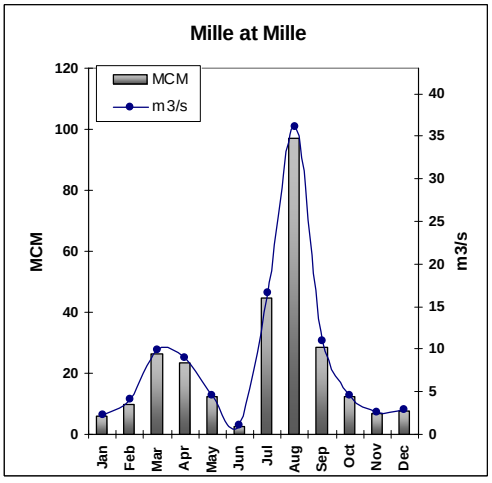
Figure 3.4b Mean Monthly Stream Flow Hydrographs at Selected Stations

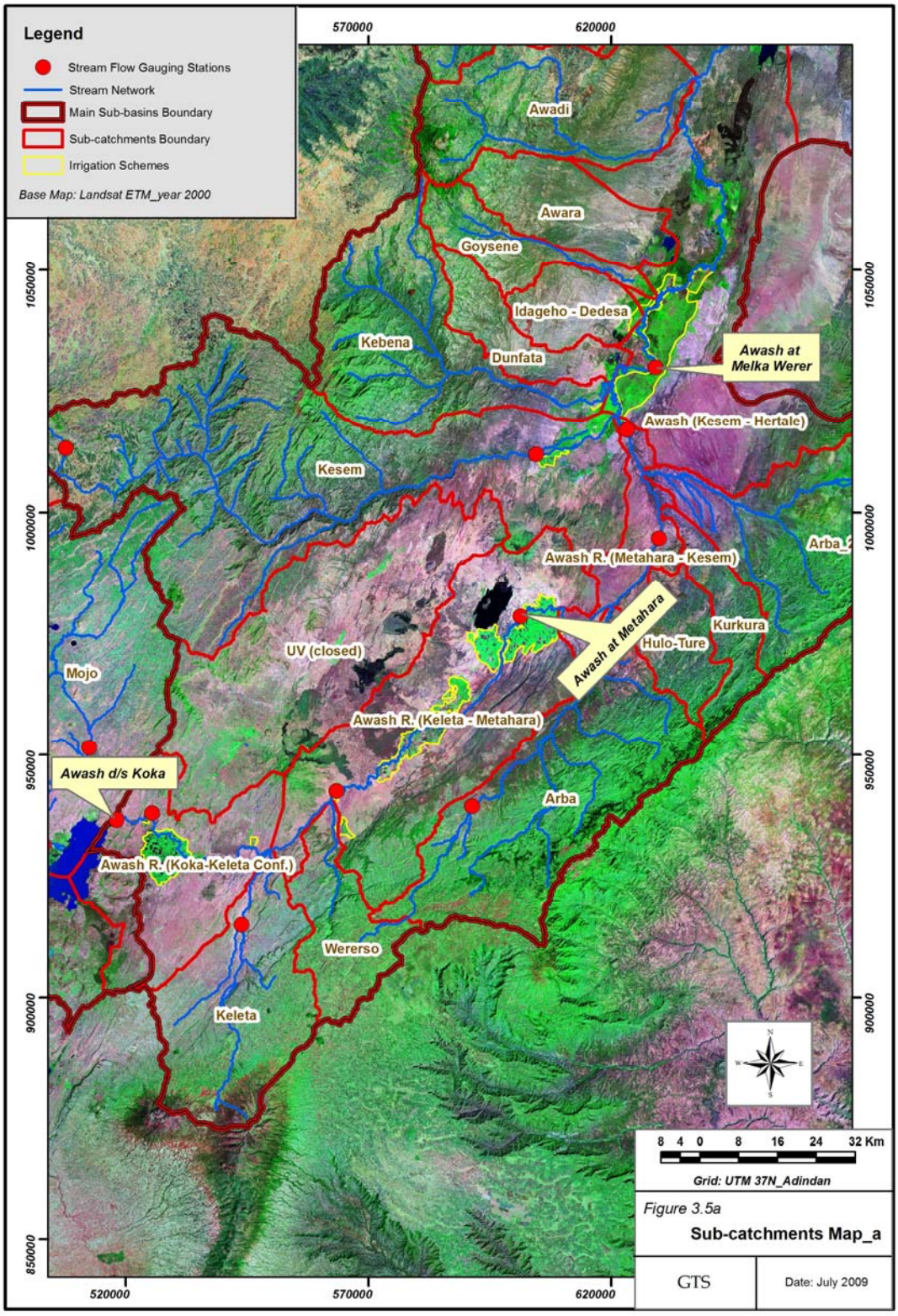


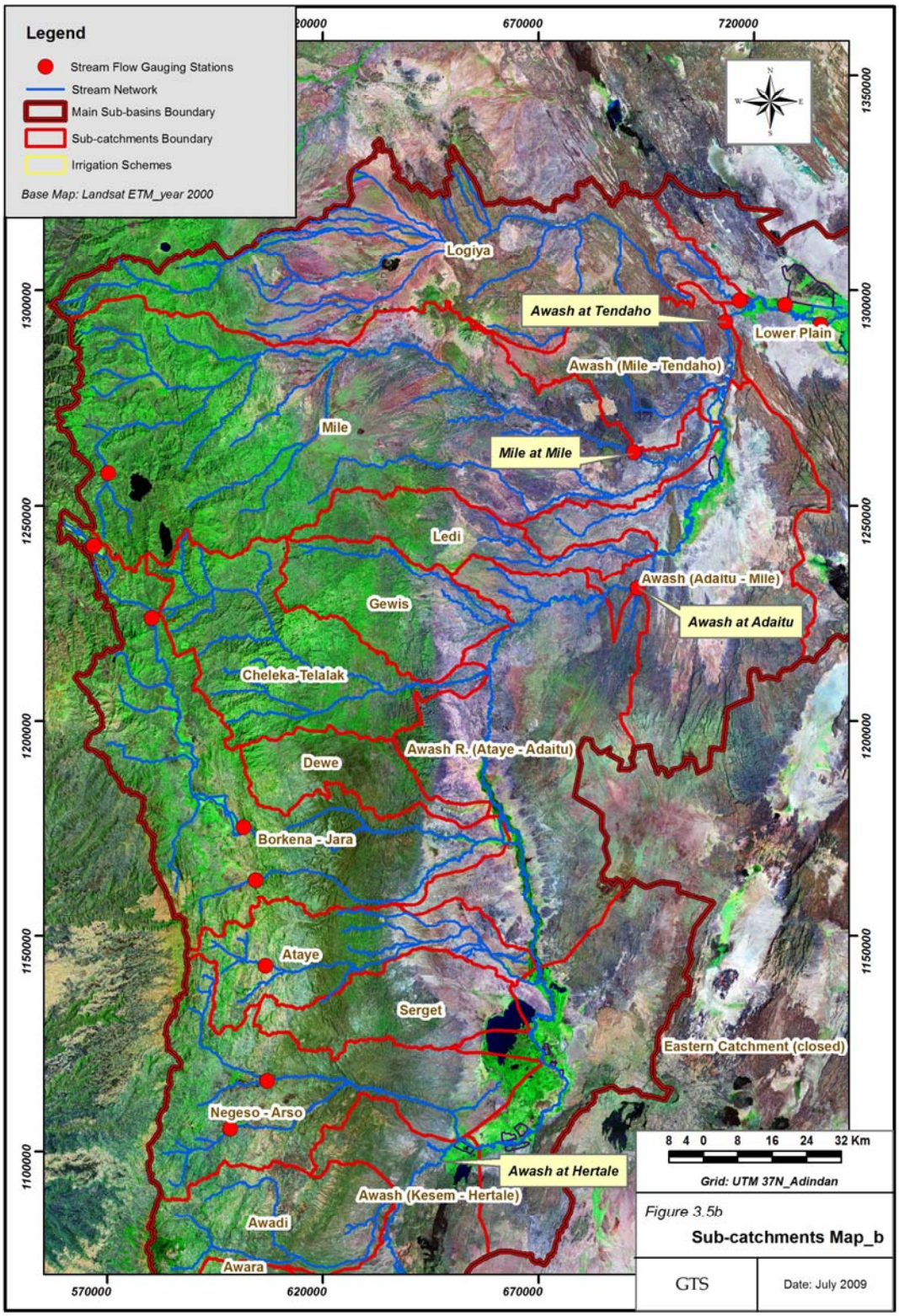









Legend
Stream Flow Gauging Stations
Stream Network
Main Sub-basins Boundary
Sub-catchments Boundary
Irrigation Schemes
Base Map: Landsat ETM_year 2000
570000
620000
1050000
1000000
950000
900000
850000
520000
Awadi
Awara
Goysene
Idageho - Dedesa
Kebena
Dunfata
Awash at Melka Werer
Awash (Kesem - Hertale)
Kesem
Awash R. (Metahara - Kesem)
Arba
Kurkura
Hulo-Ture
Awash at Metahara
UV (closed)
Mojo
Awash R. (Keleta - Metahara)
Awash d/s Koka
Arba
Awash R. (Koka-Keleta Conf.)
Wererso
Keleta
8 4 0 8 16 24 32 Km
Grid: UTM 37N_Adindan
Figure 3.5a
Sub-catchments Map_a
GTS
Date: July 2009


Legend
Stream Flow Gauging Stations
Stream Network
Main Sub-basins Boundary
Sub-catchments Boundary
Irrigation Schemes
Base Map: Landsat ETM_year 2000
670000
720000
1350000
1300000
1250000
1200000
1150000
1100000
570000
620000
670000
Logiya
Awash at Tendaho
Lower Plain
Awash (Mile - Tendaho)
Mile
Mile at Mile
Ledi
Awash (Adaitu - Mile)
Awash at Adaitu
Gewis
Cheleka-Telalak
Awash R. (Ataye - Adaitu)
Dewe
Borkena - Jara
Ataye
Serget
Eastern Catchment (closed)
Negeso - Arso
Awash at Hertale
Awash (Kesem - Hertale)
Awadi
Awara
8 4 0 8 16 24 32 Km
Grid: UTM 37N_Adindan
Figure 3.5b
Sub-catchments Map_b
GTS
Date: July 2009

3.4 The Awash River Water Balance

Preliminary assessment of the Awash river as a major surface-water resource in the valley entails computation of channel water balance with current level of irrigation development. River water balance enables to account for gains and losses of flows between gauging stations (river reaches). The channel water balance equation is:

Transmission Loss or Baseflow = (Q_{down} + I + Ech) – (Q_{up} + SRI)

Where,
Q_{up} = Flow upstream reach limit
Q_{down} = Flow downstream reach limit
SRI = Surface runoff inflow from tributaries b/n reach limits
I = Irrigation abstraction
Ech = Channel Evaporation

A number of factors were considered in selecting river reach limits for reasonable computation of the relevant channel water-budget. Prominently, the available existing gauging network on mainstream Awash and tributaries in relation to land use (mainly irrigation projects) and physiography were given weight.

Furthermore, considering recent irrigation development levels may indicate to consider a period of some years. The time aspect has been taken to be for a period of 5 hydrologic years from July 1998 to June 2003. This also indicates that for selection of reach limits, stations with recent data covering these periods could be considered.

Two major reaches have been selected: Koka Dam – Metahara and Metahara – Tendaho. The reaches delineated for the water budget are essentially long reaches. Nonetheless, in adopting such long reaches, due attention has also been given on intermediate sub-reaches to identify possible influent and effluent sub-reaches of the river in latter section.

3.4.1 Components of Channel Water Budget

Surface Runoff Inflows from Tributaries

The surface runoff contributions to the mainstream Awash between the reach limits (two selected gauging sites) were estimated by subdividing the whole contributing area into sub-catchments. For few of the significant tributaries daily flow data with relatively adequate and complete records are available for the period required. Using these data, simple catchment

area relations or other relationships discussed below were used to estimate flows at the confluence without involving any appreciable error.

For the ungauged catchments, comparisons have been made on the basis of semi-quantitative assessments with other similar nearby catchments with recorded flow data. Available flow data for the period of five years (July 1998 to June 2003) were then used to estimate the total flows at the confluences using simple statistical relations by taking into account runoff, rainfall and catchment area. With coefficient of correlation (r^2) of 0.825, the following multiple-regression equation derived by Halcrow (1989) in the Awash basin surface water resources master plan study and subsequently used by WWDSE & WPCS (2005) for the study of Tendaho dam and sugar project, has been used.

$$MAF = 0.000854 * CA^{0.80118} * (MAR - 365)^{1.00448}$$

Where,

MAF = Mean Annual Run-off or Flow (Mm^3 or MCM)
CA = Catchment Area (Km^2)
MAR = Mean Annual ainfall Depth over the Catchment (mm)

For example, Wererso sub-catchment is ungauged while the adjacent river Keleta is gauged near Sire. MAF (Mean Annual Flow or Runoff) is first calculated for both sub-catchments using the above equation; GIS watershed areas and mean annual rainfall depths (from the spatially interpolated rainfall map) are the inputs. Then Keleta flow (Q keleta nr. Sire) for the period of 5 years (July 98 – June 03) is used to calculate Wererso's inflow for the same period using the following relation:

$$Q\ inflow\ (Wererso) = \frac{Q\ keleta\ at\ Sire\ *\ MAF\ Wererso}{MAF\ Keleta\ guaged}$$

Table 3.1 gives estimates of surface runoff inflows (SRI) for contributing tributary sub-catchments. Riverside sub-catchments have also been considered and are demarcated by place names (e.g. Awash riverside sub-catchment between Metahara and Awash) despite their limited contributions. Closed sub-catchments that do not contribute surface runoff directly to Awash river have been excluded from the calculation.

Table 3.1 Estimated Surface Runoff Inflows (SRI) for Contributing Sub-catchments

Reach	Grouped Sub-catchments	SRI (MCM) (July 1998 - June 2003)
Koka Dam - Metahara		
	Keleta R.	982.962
	Wererso R.	414.618
	Awash R. (Koka Dam - Metahara GS)	654.279
	Total 1	**2051.859**
Metahara - Tendaho		
	Arba R.	1377.810
	Kesem R.	2476.170
	Kebena R.	1477.500
	Awash Arba R., Awash R. (Metahara - Awash) including Kukura & Hulo-Ture Streams	1454.500
	Awadi R., Nejeso R., Awash R. (Awash - Ataye R. Confluence)	1618.500
	Ataye R., Borkena-Jara R., Awash R. (Ataye R. - Mille R. Confluence), Choleka-Telalak R.	3293.500
	Mille R., Awash R. (Mille R. Confluence - Tendaho)	1938.514
	Total 2	**13636.494**

Irrigation Abstractions

The Awash Basin Authority (ABA), formerly known as the Awash Basin Water Resources Administration Agency, is responsible for the supply of irrigation water to the various farms (entities). In addition, the authority is responsible for the operation and maintenance of major irrigation and drainage structures. Distribution and application of the supplied water is the responsibility of the irrigators, which are the receiving entities.

Monthly amounts of supplied irrigation water for middle- to large-scale farms in the upper and middle valleys, and in the lower plains have been acquired from ABA. Table 3.2 provides the amount of water diverted to these farms from July 1998 to June 2003. Return flows estimated as percentages of the total amount abstracted have been deducted when computing the channel water balance (3-6%).

Channel Evapotranspiration

Channel evapotranspiration can be estimated by calculating the surface area of the Awash channel segments of similar geometry and taking average potential evapotranspiration in the area. Where the river passes through a big swamp such as a case in Gedebassa swamp of considerable areal extent, open water evaporation has been estimated treated separately in the next sub-section.

For the reach between Koka and Metahara, the mainstream Awash was divided into three segments while PET stations used were Wonji, Nura Hera and Metahara. As for the reach between Metahara and Tendaho, nine segments were considered with Metahara, Melka Werer, Gewane and Dubti stations for PET calculations.

Table 3.2 Irrigation Water Supplied to Farms (July 1998 to June 2003)

Location	Farms	Irrigation Diversion (1000 m^3)
Upper Valley	Wonji / Shewa Sugar Estate	425549.9
	Upper Valley Agro Complexes	886841.9
	Others	93420.7
	Total 1	1405812.5
	Metahara Sugar Estate	
	Abadir	453247.6
	Merti	888430.1
	Total 2	1341677.7
Middle Valley	Amibara Irrigation Schemes & Angelele	
	Melka Sadi Cotton (MAADE)	92154.7
	Former Melka Sadi Banana (MAADE)	80170.4
	Melka Werer Cotton (MAADE)	207334.0
	Total 3	379659.1
	EARO / Werer Research Center	19630.1
	Amibara Agricultural Development Ent.	211012.4
	Africa Agricultural Development Ent.	24077.8
	Other Private Farms	53574.8
	Total 4	308294.9
	Gewane, Burayto Plain (Bure Modaytu) & Be Adu Area Farms	38240.0
Lower Plains		
	Dubti, Dit Bahari and other farms	604368.0

3.4.2 Results

The Awash river receives considerable amount of surface-runoff inflows from the western sub-catchments. In the reach between Metahara and Tendaho, an estimated total five years inflow from tributaries is about 13.5 BCM (billion cubic meters). About 60 % of this amount has been acquired upstream of Gewane while the rest (about 40%) downstream of Gedebassa swamp (see Table 3.1). On the other hand, some 2.1 BCM of surface water inflow to mainstream Awash in the upper valley has been estimated for the same period. These values may indicate that on average the Awash river could receive surface inflows of about 2.7 BCM /year between Metahara and Tendaho, which is more than the five years' total contributions from the upper valley sub-catchments.

Referring to Table 3.2, nearly 50% of overall total abstractions have occurred in the upper valley. The two large sugarcane estates Wonji-Shoa and Metahara, and Merti Jeju and Nura

Hera farms (Upper Awash Agro-Industry) take the big shares. In addition to their sizes, perennial crops like sugar cane and tree fruits are grown in these farms that require irrigation throughout the year.

In the middle valley, considerable amount of irrigation water has been supplied to farms of Amibara Irrigation Schemes (AIS). The abandonment of Dofen-Bolhamo, Haledebi, Mille and partly Angelele farms in the middle and lower valleys has made the total abstractions in the reach between Metahara and Tendaho to be lesser than it had been in the 80's. Although certain figure has been given for lower plains' farms for the sake of general comparisons, the amount abstracted has not been taken into account in the channel water balance computation, as Tendaho station is located upstream of the farm's intakes.

The Awash river water balance computed for the period July 1998 – June 2003 is presented in Table 3.3. Referring to the channel water balance equation above, the residual value obtained by subtracting the total ouflow from the total inflow gives the baseflow (if +ve value) or transmission loss (if -ve value). While baseflow may show substantial groundwater discharge to river, transmission loss may give potential recharge amount for the reaches considered.

The computed channel water balance for the reach between Koka dam and Metahara yielded a loss of about 2.1 BCM during the five year period (i.e. on average of about 400 MCM/yr).

Significant amount of transmission loss of some 6.8 BCM has been estimated in the reach between Metahara and Tendaho. The amount is relatively higher and may include recharge as well as loss due to over-bank flooding and subsequent evaporation. For example, the Gudebasso swamp forms a major transition in that considerable flow loss occurs when the main river course passes through this seasonally changing swamp. Another notable site may be the lower valley downstream of Adaitu area where traces of abandoned channels can easily be identified on satellite images.

Following these, evapotranspiration was calculated for the largest Gedebassa vegetated swamp area by taking into consideration effective swamp area and mean PET rate at Gewane. The average amount of water evaporation rate computed is about 500 MCM/yr with effective area of 330 km^2. Deducting this from the average yearly amount (1.37 BCM) gives a balance of 870 MCM/yr.

Table 3.3 Awash River Water Balance (July 1998 – June 2003)

Reach	Water-Budget Components	MCM (July 1998 - June 2003)	
Koka Dam - Metahara			
	Q upstream (Awash below Koka Dam)	9180.700	
	Q dowstream (Awash at Metahara)		6490.183
	SRI b/n Koka Dam - Metahara	2051.859	
	Irrigation Abstractions		
	Wonji/Shewa, Upper Valley Agro Complexes & Others (including the Wonji Out growers)		1321.464
	Metahara Sugar Estate (Abadir)		439.650
	Metahara Sugar Estate (Merti)		844.008
	Total		2605.122
	Channel Evaporation		47.7
	Transmission Loss		**2089.507**
Metahara - Tendaho			
	Q upstream (Awash at Metahara)	6490.183	
	Q dowstream (Awash at Tendaho)		12308.061
	SRI Metahara - Tendaho	13636.494	
	Irrigation Abstractions		
	AIS State (MAADE) Farms		364.473
	AIS others		295.963
	Gewane area farms		36.710
	Total		697.146
	Channel Evaporation*		270.1
	Transmission Loss		**6851.365**

** only includes the Awash channel; Gedebassa swamp area evaporation not included*

3.5 Discussion

Climate (particularly rainfall) noticeably affects the stream flow amount and pattern in the Awash Basin. The mean monthly flows of the mainstream awash (in the middle and lower valleys) and the tributaries are characterized by uni- and bi-modal type of flow regime fairly reflecting the highlands rainfall regimes identified. The runoff generated is also essentially governed by the topography, the soil and vegetation characteristics. The physiographic factors greatly affect runoff in that they also influence the landuse and agricultural development within the Awash basin.

In addition to the primary natural factors, human influences have also impacts on the flow characteristics of the Awash river. Of great importance to consider are the dam constructed at Koka for hydro power generation and the irrigation abstractions for the medium- to large-

scale agricultural developments within the basin, which together contribute to significant modifications.

Surface irrigation is the irrigation method practiced in the Awash valley. The overall efficiency of such irrigation system is relatively lower (usually less to equal to 50%) that large amounts of water is abstracted than necessary. In Awash valley, substantial amounts of water are abstracted by the upper valley schemes that substantially affect the downstream schemes. The next chapter addresses efficiency of the Amibara Irrigation Schemes (AIS) in the middle valley with other related irrigation practice and water management issues.

Having said these, the next in line is discussing the channel water balance. Before doing so, valuable hydrogeologic notes mainly on groundwater occurrence and movement have been briefly forwarded in the coming few paragraphs. It is intended to link the results of channel budget with lithology (alluvial or volcanic), permeability and groundwater flow to study the interactions between surface and groundwater systems.

In large Basins like the Awash, a great deal of spatial variability in recharge mechanism and amount exists at different scales. Direct recharge from precipitation is more important on the highlands than in the lower plains. Indirect recharge from streams in semi-arid and arid regions of the rift valley could be significant as compared to direct recharge from precipitation. In some areas, such streams literally recharge through stream bed infiltration by providing aquifers with substantial quantities of water.

The various volcanic rock units of the Awash basin can collectively be grouped as the Trap series and rift rocks, comprising mainly the highlands and the rift respectively. Comprehensively, these volcanic rocks constitute extensive and localized aquifers of mainly fracture permeability (Tesfaye Chernet, 1993).

Covering considerable part of the rift floor, the alluvial and lacustrine sediments form extensive aquifers with intergranular permeability. The monotony of the flat alluvial deposits of the rift floor is disrupted by numerous volcanic piles and faults. This results in interruption of the lateral continuity of the alluvial aquifers but groundwater in these formations may still be in hydraulic contact in various places.

It is important to note that wide range of productivity is exhibited by the various geological units due to local and regional conditions (Getahun Kebede, 1987; Tesfaye Chernet, 1993). In as much as the geology (lithology and structures), the various aspects of climatic

conditions influence groundwater occurrences on the highlands as well as in the valleys and plains of the Awash basin.

The regional groundwater flow in the Awash valley is generally from the upper valley to the lower plains (UNDP, 1973). Halcrow (1989) have also indicated that groundwater in parts of the valley is derived from the escarpments. The importance of faults and fractured rocks for recharge from runoff on the escarpment regions has been indicated by Getahun Kebede (1987). While these conditions may show that groundwater movement is controlled by topography, the various structures (faults or fracture zones) also play their roles acting as groundwater conduits and in some places as groundwater barriers.

The channel water balance exercise has shown that the Awash river is generally influent. This may indicate that the groundwater tables of the adjacent aquifers are generally lower in some places or there are certain reaches that may favor recharge due to relatively higher permeability of the aquifers or presence of structures (faults, fracture zones or joints).

Alluvial and lacustrine deposits cover vast areas of the valleys and plains of the Awash basin with varying thickness. These sediments have variable permeability due to grain size differences. Zenaw Tessema (1998) mentioned the presence of a highly permeable river bed, south-east of Abadir farm, and a very high permeability river reach south of Metahara as possible zones of transmission loss in the upper valley. In few sub-reaches, the Awash river flows through structurally controlled volcanic gorges comprising fractured formations.

On the other hand, groundwater is encountered at variable depths at different localities. While the aquifers underlying the main river reveal different hydrogeological characteristics, both alluvial and volcanic aquifers exist resulting in variable continuity with the main river. In the alluvial floodplains, the groundwater in irrigation areas is encountered at shallow depth. The Awash river is supposed to be in direct hydraulic connection with the groundwater in the alluvial sediments. Therefore, mainstream Awash receives groundwater inflow, i.e. effluent conditions particularly during the dry period. In addition, sub-reaches close to permanent surface water bodies should be noted. The area downstream of Koka is a typical example that receives considerable groundwater inflow from reservoir leakage.

CHAPTER FOUR

SURFACE IRRIGATION: THE AMIBARA IRRIGATION SCHEMES (AIS)

4.1 Introduction – The Case Study Area

The Amibara irrigation schemes cover a long broad alluvial plain along the right bank of the Awash river, locally known as Melka Sadi and Amibara with a gross command area of about 15 000 ha. Source of irrigation water is the Awash river by making use of diversion weir at Melka Sadi and several pumps downstream of Melka Werer town.

Until very recently, more than 50 % of the command area used to be managed by the Middle Awash Agricultural Development Enterprise, which comprised three independently managed state farms, namely the former Melka Sadi banana unit, Melka Sadi- and Melka Werer-cotton farms. Other farms include Werer Research Center farm, former Amibara settlement farm, Algeta, Ambash and Sublale farms (see Figure 4.10). With regards what were the previously state farms, they are now under a privately owned enterprise.

The principal crop grown in AIS is cotton (Gossypium hirsutum). Few other crops like sesame, banana, and vegetables are grown in limited plots of the Research Center. Banana used to be grown in the former Melka Sedi banana unit, which was later on replaced by cotton between 2001 and 2002. Maize used to also be grown partly in the former Amibara settlement farm in the 80's.

4.2 Climate and Crop Water Requirement

4.2.1 Climate

Hydro-meteorological data were made available for two relevant stations in the area. The agricultural research center at Melka Werer provided all the pertinent data that included daily and monthly records of rainfall, temperature (minimum, maximum and mean), pan evaporation, relative humidity, sunshine duration, wind speed and soil temperature. For Awara Melka, daily rainfall data were obtained from the National Meteorological Services Agency (NMSA).

Rainfall

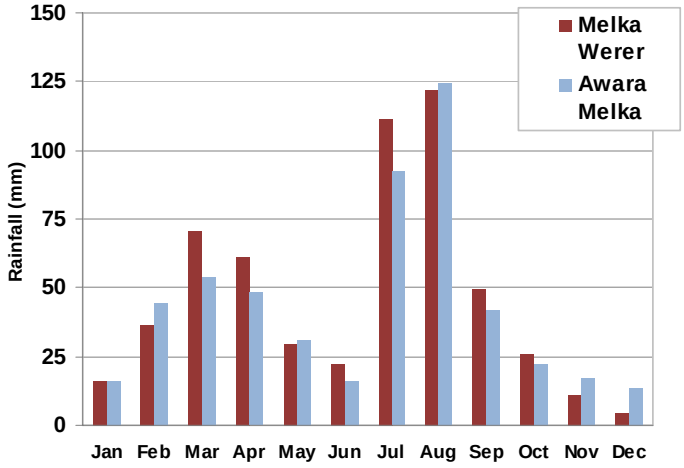
Figure 4.1 shows monthly rainfall distributions at Melka Werer and Awara Melka stations. It has been previously mentioned that the ITCZ mainly influences rainfall distributions across the basin and also that bi-modal type of rainfall characterizes the Awash valley. The figure portrays the "Belg" and "Kiremt" rainy season's durations from February-May and July-

September respectively. Nonetheless, the relative importance of the months February, May and September may not significant as compared to March and April, and July and August that form the monthly average peaks in their respective seasons.

Comparisons of the stations' long-term annual mean show that there is variation in rainfall amount along the long-stretched irrigation schemes. The mean annual rainfalls at Awara Melka, and Melka Werer Amibara are 522.7 and 561.7 mm respectively. Of much importance, the Melka Werer station is located in the middle part of project area. In close proximity to the Melka Sadi plains of the project area is the Awara Melka station, situated at Awara Melka farm (east of Dofen Mt.) which may together help explain the variation in rainfall distributions.

With the above conditions, it was found necessary to consider spatially averaged conditions rather than using point measurements at one gauge. The fact that the positions and the density of the stations are fairly optimum and also that the stations have long period of records, the advantage of using the simple arithmetic average of the two stations was forwarded to represent rainfall depth over the 15, 000 ha schemes. The average areal rainfall depth calculated is 542.1 mm, which is a reasonable value for the area.

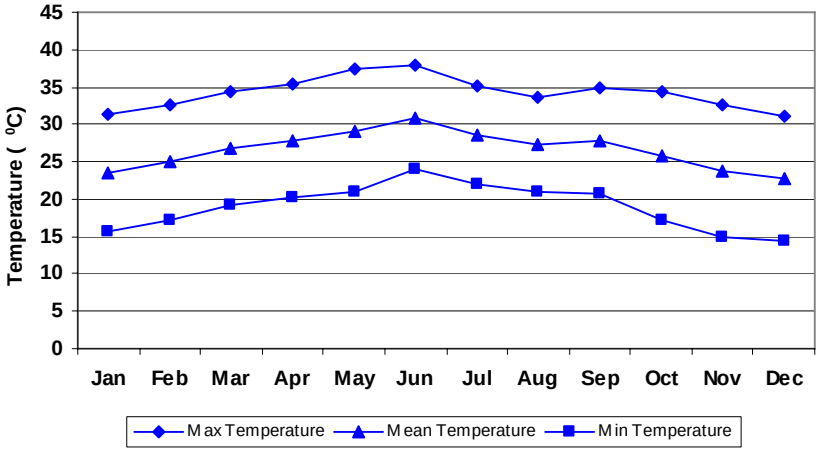
Figure 4.1 Rainfall Distributions at Melka Werer & Awara Melka



In view of the need to properly estimate reference crop evapotranspiration in addition to describing the general climatic condition of the Amibara area, temperature, relative humidity, wind speed, sunshine duration and pan evaporation data at Melka Werer station were initially analyzed.

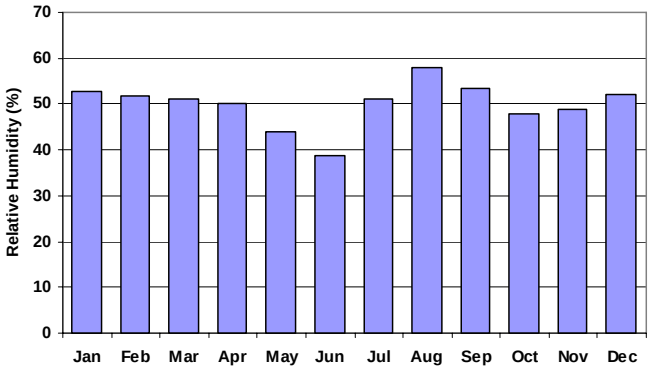
The long term mean annual temperature at Melka Werer is 26.6 ^{o}C. As shown in the Figure 4.2, the mean daily maxima and minima temperatures show similar pattern in that the long term average (mean) correspondingly follows the trend. Temperatures gradually rise from January to attain peak values in June which is just before the beginning of the main rainy season. After June, temperatures go down during the months of July and August before it again rises in September and then gradually decline to reach the lowest value in December, which is the middle of the dry season.

Figure 4.2 Temperature Variations at Melka Werer (max, mean, min)



In contrast to temperature, relative humidity at Melka Werer tends to follow an inverse trend (Figure 4.3). While June is the month with the lowest recorded mean value, humidity is higher during the main rainy season, August being the highest. The long term mean annual humidity is computed as 50%, which is well above the mean values of May and June (43.9 and 38.8 % respectively).

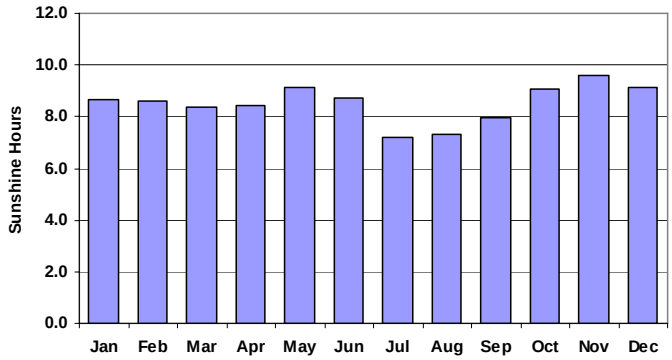
Figure 4.3 Relative Humidity at Melka Werer



Mean daily sunshine hours at Melka Werer are shown in Figure 4.4. Daily sunshine hours decrease during the two rainy seasons. The main rainy season from July to September is

clearly represented with lower levels (less than 8 hrs). On the other hand, the main dry season from October to December and the month May have relatively higher mean values, November being the highest (9.6 hrs).

Figure 4.4 Daily Sunshine Duration at Melka Werer



Wind speed records at Melka Werer are available for measurements at 1 and 2m; the latter was taken as it is usually recommended as a standard for estimating crop water requirements. During data processing discrepancies between the daily and monthly data were noticed. While km/hr is given as the unit for the daily data, the reported monthly data is in m/s. Comparisons of the data with other nearby stations (Metahara, Awash and Gewane) revealed that the daily data in km/hr is acceptable and that the reported unit of the monthly data is incorrect.

Figure 4.5 Wind Speed at Melka Werer

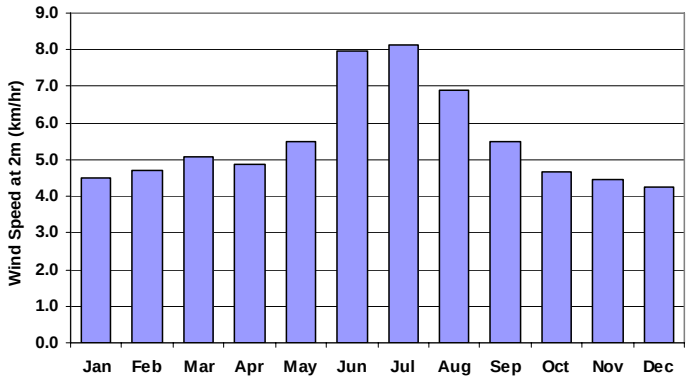
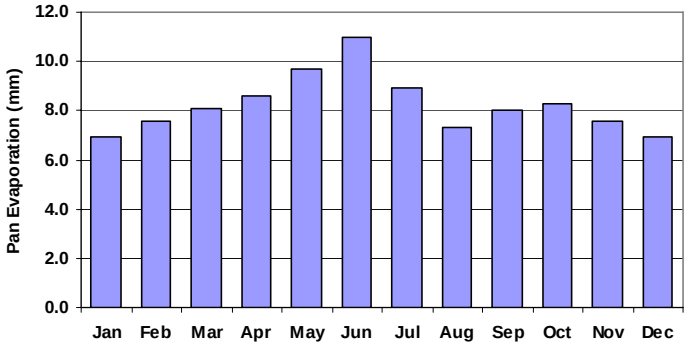


Figure 4.5 shows the measured wind speeds at Melka Werer. Recorded mean daily wind speeds are higher during the months of June and July followed by August, making the pattern rather a unimodal type with their relatively elevated magnitudes. The long term mean annual wind speed computed is in the order of 5.5 km/hr. Comparable values were obtained

by previous studies (Halcrow, 1983; Haider and Kandiah (1988); old climatic data of FAO/CropWat).

Evaporation measurements from a Class A pan at Melka Werer are shown in Figure 4.6. Evaporation rates are higher during the months of May and June. With recorded highest temperatures, lowest relative humidity and higher wind speed taking place in June, it is justifiable that mean pan evaporation rates attain the highest value (11 mm/day) just prior to the main rainy season. On the other hand, December and January record the lowest mean evaporation rate (6.9 mm/day). The calculated mean pan evaporation rates are used to calculate reference crop evapotranspiration in next section for comparison purpose.

Figure 4.6 Pan Evaporation (Epan) at Melka Werer



4.2.2 Reference Crop Evapotranspiration

Reference crop evapotranspiration (ETo) for Amibara Irrigation Schemes has been computed here based on historic climatic data. Among the available methods, monthly ETo estimates have been calculated using pan and Penman-Monteith methods.

FAO irrigation and drainage paper no. 24 (Doorenbos and Pruitt, 1992) relates pan evaporation to reference crop evapotranspiration by introducing a pan coefficient (Kp), which depends on the siting of the pan and pan environments. The recommended relationship is expressed in an equation form as:

$$ETo = Kp \cdot Epan$$

Where,

ETo = reference crop evapotranspiration in mm/day

Epan = pan evaporation in mm/day

Kp = pan coefficient

Taking into consideration the type and location of the Melka Werer pan, relative humidity and wind speed mean values on monthly basis, appropriate Kp values were selected by referring to the climatological nomenclature and pan coefficient tables provided in Doorenbos and Pruitt (1992).

With all the necessary climatic data being available, reference crop evapotranspiration was subsequently calculated using the Penman-Monteith method. The software CropWat was used to compute ETo on monthly basis by entering the previously calculated mean monthly min and max temperatures, relative humidity, wind speed and sunshine duration of Melka Werer station.

As it can be seen in Tables 4.1 & 4.2, comparable annual ETo rates were obtained using the pan evaporation and Penman-Monteith methods with values of 1924.8 and 1970.0 mm respectively. While quick and fairly reasonable estimates can be obtained using pan evaporation data, the Penman-Monteith is highly recommended by FAO as being a reliable method for estimating reference crop evapotranspiration. For the purpose of this study, ETo computed using the Penman-Monteith is taken to estimate crop water requirements as well as irrigation requirements (net and gross) and irrigation scheduling in the following sections.

Table 4.1 Reference Crop Evapotranspiration (ETo) using Pan Evaporation method

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Epan (mm/day)	6.9	7.6	8.1	8.6	9.7	11.0	8.9	7.3	8.0	8.3	7.6	6.9	
Kp	0.65	0.65	0.65	0.65	0.65	0.60	0.60	0.65	0.65	0.65	0.65	0.65	
ETo (mm/day)	4.49	4.94	5.27	5.59	6.31	6.60	5.34	4.75	5.20	5.40	4.94	4.49	
ETo (mm/month)	139.0	138.3	163.2	167.7	195.5	198.0	165.5	147.1	156.0	167.2	148.2	139.0	1924.8

Table 4.2 Reference Crop Evapotranspiration (ETo) using Penman Monteith method

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Maximum Temperature (^{o}C)	31.3	32.7	34.5	35.5	37.3	37.9	35.2	33.5	34.9	34.3	32.5	31.2	
Minimum Temperature (^{o}C)	15.7	17.3	19.3	20.2	21.0	23.9	21.9	21.1	20.7	17.3	14.9	14.5	
Relative Humidity (%)	52.7	51.8	51.2	50.1	43.9	38.8	51.2	58.1	53.3	48.0	48.9	52.0	
Wind Speed at 2m (km/hr)	4.5	4.7	5.1	4.9	5.5	8.0	8.1	6.9	5.5	4.7	4.5	4.3	
Sunshine Duration (hr)	8.7	8.6	8.3	8.4	9.1	8.7	7.2	7.3	7.9	9.1	9.6	9.1	
ETo (mm/day)	4.43	4.92	5.45	5.62	6.10	6.95	6.02	5.46	5.51	5.26	4.74	4.30	
ETo (mm/month)	137.3	137.8	169.0	168.6	189.1	208.5	186.6	169.3	165.3	163.1	142.2	133.3	1970.0

4.2.3 Crop Water Requirements

Crop water requirement has been calculated for cotton as it is currently the sole crop grown in Amibara, expect in small Werer Research Center plots. ETcotton was calculated using the computed ETo data (Penman-Monteith method) and crop data collected from the Werer Research Center and FAO publications.

Previous Studies

Cotton water requirements have been calculated for Amibara irrigation schemes at different times using ranges of data and various approaches.

- Halcrow (1983) estimated the crop water requirements for a growing period of 145 days by considering the 3 rd and 15 th of May as planting dates and came up with values of 892.10 and 876.89 mm respectively. For both estimations, reference crop evapotranspiration (ET_O) was calculated using the modified Penman method on monthly basis.
- On the other hand, Haider and Kandiah (1988) estimated the cotton water requirements for each growth stage and for each month during the growing season. Reference crop evapotranspiration values were calculated using the modified Penman and pan evapotranspiration methods. For the selection of appropriate pan coefficient, a pan of a US Class A placed in dry fallow area with medium mean relative humidity and low wind speed conditions were inferred. A total growing period of 165 days was considered and appropriate values of K_C were selected to be used in the two approaches. Accordingly, the growth stage-wise and month-wise cotton water requirements gave 974 and 963 mm respectively.
- Alternatively, the cotton water requirements recently determined by Shimels (2004) considered the planting date on the 15th of April. Suitably, the FAO Penman-Monteith method was used to determine the reference crop evapotranspiration. Following the procedures outlined by FAO (1998), the calculations for the requirements were made on ten-day basis for the growing period between April 15 and December 11. Accordingly, the study came up with an estimated ET cotton value of 1080.8 mm.

ET cotton, this study

As mentioned above, earlier studies had considered the planting date of cotton in the study area as the first and second week of May. With a slight shift in the planting date, it was

however observed during the field visit in 2003 and 2004 that some blocks of fields started sowing in Mid-April. This may have been attributed to the largeness of the AIS with varying sized blocks of farms managed independently by the state farm and a number of private investors. In this respect, other interrelated factors like the operational status and capacity of the different enterprises may have also influenced. In addition, various water management issues like the type of system serving the various blocks (gravity offtake or pump supplied), availability and allocations of irrigation water and so on may have also brought about this shift. It was understood for these or other reasons that the planting date extends upto end of May. Some fields are even late planted in June.

The growing periods and approximate duration of the growth stages of some of the main crops in Middle Awash Valley are provided in Haider and Kandiah (1988), as prepared in collaboration with Werer Research Center. The relevant data for cotton growing in the study area was adopted with slight modification on the number of growth stages in order to suit the data requirements of the model CropWat. Regarding the data as representative for cotton planted between Mid-April and May, the durations for the initial, crop development, mid-season and late-season stages are taken as 20, 30, 65 and 50 days, summing up to a total growing period of 165 days.

It follows that after obtaining the above pertinent data, the next step is to select appropriate crop coefficients. Locally determined Kc values directly applicable to cotton grown in the study area are not available. In such case, it may be necessary for each growth stages to select appropriate Kc values from FAO publications. The crop coefficient values for initial, mid and late –season stages taken respectively are 0.4, 1.15 and 0.65; no value is required for the crop development stage.

Once values of ETo, crop data and pattern are entered, ETcotton can be determined on daily, weekly, 10-days or monthly basis. Since cotton cannot be planted all at the same time on April 16th in all ten blocks, as stated earlier the cotton planting date is taken to extend upto end of May. The last harvesting date will then be November 12. Nonetheless, harvesting is known to extend till December in Amibara, particularly allowing double picking of cotton.

The CropWat model calculates the crop water requirement using the following equation:

CWR = ETo x Kc x AP

Where,
ETo = Reference Crop Evapotranspiration (mm/d)
Kc = Crop Coefficient
AP = Area Planted (%)

The reference crop evapotranspiration (ETo) and cotton water requirements (ETcotton) calculated for the season are 1216.19 mm and 889.55 mm respectively (see Table 4.3 for 10-days calculation).

4.3 Soils of the Amibara Irrigation Schemes

The parent materials of the alluvial deposits in rift valley of the study area are volcanic rocks. Weathered materials from the volcanic highlands have been transported and deposited in Middle Awash Valley by the Awash river and its tributaries.

As part of this study, a total of 556 soil samples were systematically collected from Amibara Irrigation Schemes during the field work in 2004. The particle size distributions of these soil samples were determined in laboratory using hydrometer method in which sodium hexa-metaphosphate was used as a dispersing agent. Having the proportions of sand, silt and clay determined, the soils textural classes were determined using the standard soil textural triangular chart. The chemical analyses results are interpreted in Chapter 7 while this section will address the physical properties of the AIS soils.

Figure 4.6 shows the general soils map of the Amibara Irrigation Schemes. In order to group the various soils into mapping units, the current soil survey data as well as other compulsory information were taken from previous surveys (Sogreah, 1965; Italconsult, 1969; Halcrow, 1983; Haider and Kandiah 1988). The main soil types of the Amibara irrigation farms have been classified as recent alluvia and vertisols in these previous studies. In this study, the soils are preferably grouped as medium-textured and heavy-textured soils.

The medium-textured soils are dominantly silt loam, silty clay loam and loam. Occasionally clay loam soils are encountered and are included in this unit. Soils of this unit are yellowish brown or light brown when dry and turn dark brown to very dark grey brown when wet. The former Melka Sadi farm as well as farms bordering the Awash river and the main canal downstream of Melka Werer town are covered by such type of soils. Relatively coarser loamy and sandy soils containing significant amounts of gravels and cobbles are mapped as a separate unit (*Gravelly*) with limited extent along the main canal bordering the Melka Sadi farms on the eastern side.

The heavy-textured soils have relatively high proportions of clay as compared to the medium-textured soils. Predominant textural classes are clay and silty clay; hence, they may also be called clayey soils. Clayey soils over loamy soils are also included in this unit as the clay content is observed to decrease with depth in some places. Soils of this unit are dark grey

when dry and black when wet. Well-defined blocky or prismatic structure could develop. They may show typical vertic or black-cotton soil properties. Characteristic to clayey heavy soils is the development of shrinkage cracks during the dry period. Cracks disappear with increasing soil moisture and swell after events of rainfall or irrigation. They become very sticky when soggy. This unit covers substantial part of the Melka Sadi and Melka Werer cotton farms as well as the north eastern farms (see soil map).

Some of the important physical characteristics of soils usually determined or measured other than particle size distribution (texture) include porosity, bulk density, field capacity, permanent wilting percentage, soil permeability and infiltration.

Determining porosity is important in assessing the water storage capacity of a soil. Generally, the heavy soils have relatively higher porosity than the medium-textured soils. Computing the values reported in Halcrow (1983), the average porosity percentages were estimated for the heavy and medium soils as 50 and 45 respectively. The bulk densities reported in Halcrow (1983) and Haider and Kandiah (1988) range 1.2-1.4 and 1.1-1.3 for the medium- and heavy-textured soils.

The field capacity and permanent wilting percentage of soils are similarly influenced by texture. Field capacity (FC) is the water content of a soil after the saturated soil has drained under gravity usually for about two to three days while permanent wilting point (PWP) can be defined as the water content of a drying soil at which plants permanently wilt. Haider and Kandiah (1988) have provided representative ranges for field capacity and permanent wilting point on weight basis for the soils of Amibara farms. The reported percentages for the medium-textured soils range from 30-50 for FC and from 15-30 for PWP whereas the heavy soils have FC and PWP ranges of 35-55 % and 20-35 % respectively.

Taking average characteristic values for FC, PWP and bulk density, total available moisture (TAM) calculated for the heavy clayey and fine-medium textured soils are 220 mm/m and 190 mm/m respectively. Values of over 250mm/m and lower than 150mm/m have been reported for some soil samples. While the TAM is considered as moisture available for plant use between the field capacity and permanent wilting point, the readily available soil moisture however is usually taken as the 50 - 65% of the TAM (see depletion coefficient for cotton in next section). Hence, the heavy soils have relatively higher readily available moisture (RAM) than the medium-textured soils.

Due to variations in texture vertically as well as horizontally, permeability and infiltration of the soils are likely to vary to some extent in Amibara irrigation schemes. The top alluvial

sediments of AIS are mainly fine to medium textured and are characterized by relatively low permeability. This however does not mean that deep percolation of excess irrigation does not exsit. The infiltration rates given in Haider and Kandiah (1988) for the medium- and heavy-textured soils of Amibara farms range from 10-35 mm/hr and 2-10 mm/hr respectively. Nonetheless, it is important to note that soil sodicity and/or salinity can bring about noticeable local variations; so does cultivation. With good management, the structure of the soil can become better so that the volume of pores and cracks does not decrease to affect infiltration. Cultivating when wet, on the other hand, adversly affects the structure of the surface soil.

4.4 Irrigation Requirement & Scheduling

Net irrigation requirement (NIR) for a crop may be defined as the depth of water application over the entire growing season to supplement rainfall as well as stored soil water and contribution from groundwater. It can be calculated using the field water balance, expressed in equation as follows (Doorenbos and Pruitt, 1992):

NIR = Et crop – Pe - Ge - Wb

Where,
NIR = Net irrigation requirement (mm)
ET crop = Crop water requirements (mm)
Pe = Effective rainfall (mm)
Ge = Groundwater contribution
Wb = Stored soil water at the beginning

As not all rainfall is effective for plant growth, effective rainfall is considered as that portion of rainfall available for cotton growth during the growing season. This can be attributed to the fact that part of the rainfall is lost by evaporation from intercepted rainfall, by runoff and by deep percolation below the root zone.

Rainfall considerably varies both seasonally and annually in Amibara, indicating the need to consider dependable rainfall for estimating effective rainfall. Bearing in mind that the monthly rainfall values show variations from year to year, probabilities of 70, 75 and 80 % were initially statistically derived from the long term (30 yrs) Melka Werer rainfall data. For the relevant months of the cotton growing period, the 75 % probable rainfall was observed to have comparable rainfall totals as compared to the three relatively drier years selected. In addition, the monthly rainfall distributions obtained were also observed to better fit the regional rainfall pattern.

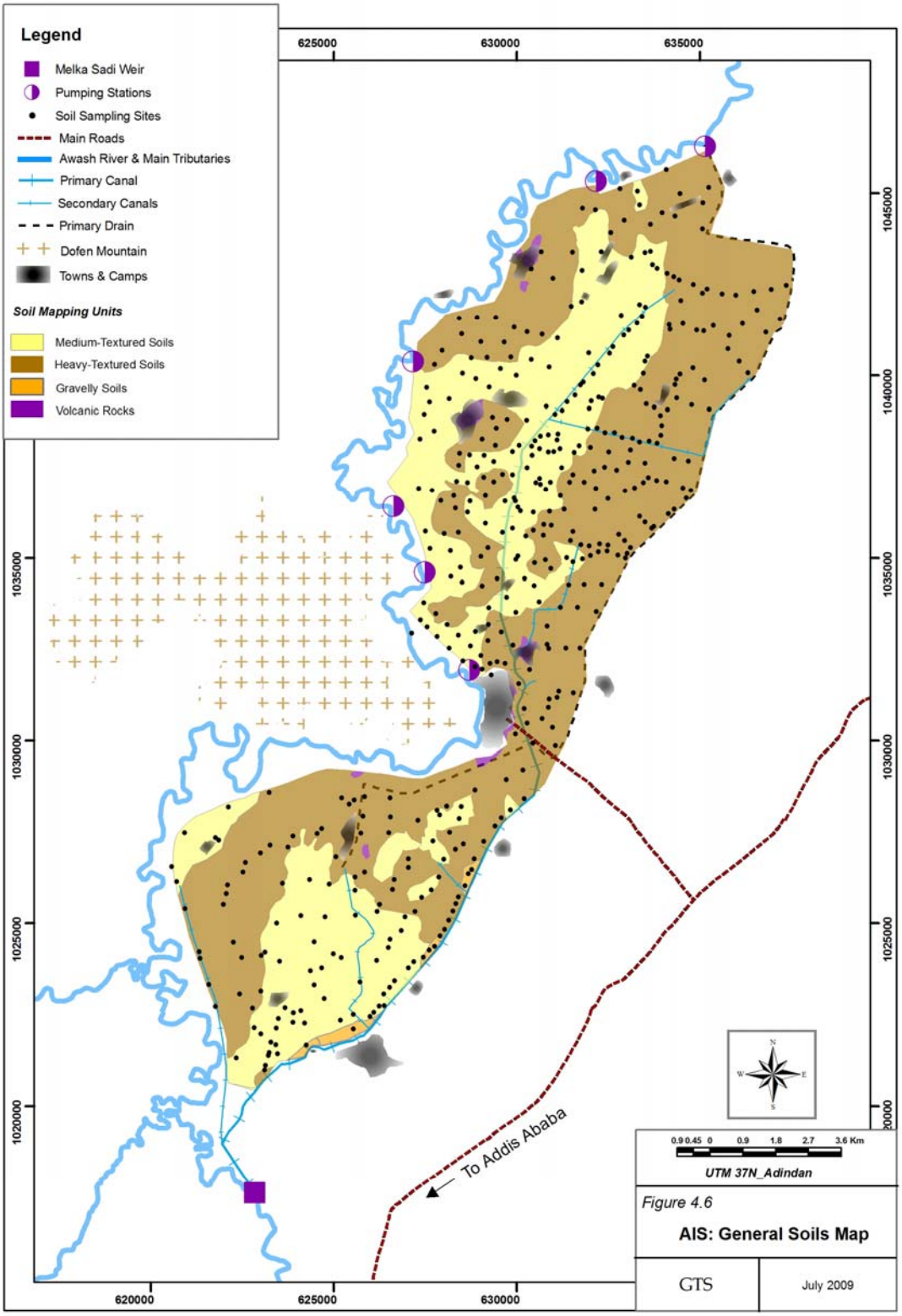
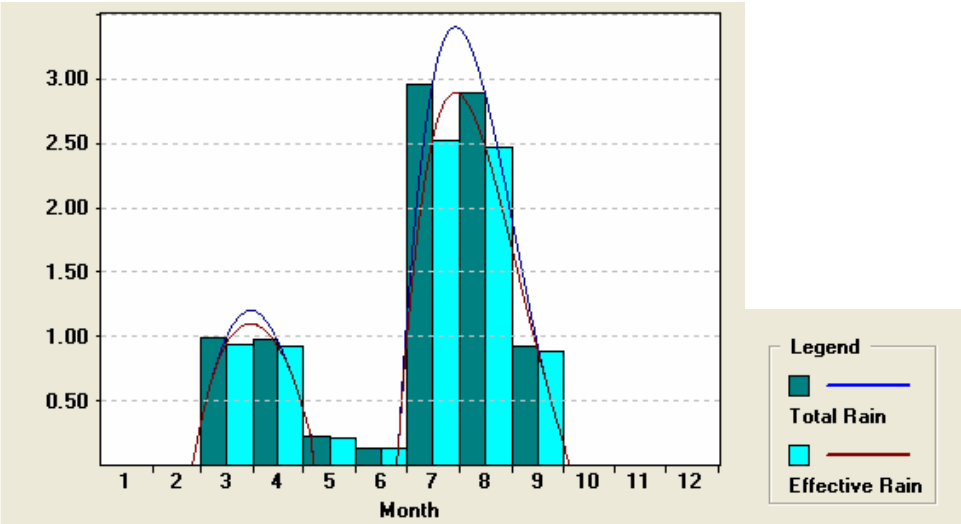

Legend
Melka Sadi Weir
Pumping Stations
Soil Sampling Sites
Main Roads
Awash River & Main Tributaries
Primary Canal
Secondary Canals
Primary Drain
Dofen Mountain
Towns & Camps
Soil Mapping Units
Medium-Textured Soils
Heavy-Textured Soils
Gravelly Soils
Volcanic Rocks
625000
630000
635000
1045000
1040000
1035000
1030000
1025000
1020000
620000
To Addis Ababa
0.9 0.45 0 0.9 1.8 2.7 3.6 Km
UTM 37N_Adindan
Figure 4.6
AIS: General Soils Map
GTS
July 2009

Figure 4.7 shows the effective rainfall estimates (mm/day) using USDA Soil Conservation Service (SCS) method taking the 75 % probable rainfall (3 out of 4 years) as total rainfall. The monthly estimates of effective rainfall for the entire year have been distributed using polynomial curve fitting, found reasonable for the growing period (Mid-April to November). The effective rainfall (Pe) estimated for the season is some 207 mm which is used to compute seasonal NIR, assumed to provide the likely reliable NIR (see Table 4.3).

Figure 4.7 Total and Effective Rainfall Graph (mm/d)



Determination of groundwater contribution requires systematic and detailed experiments on site. The groundwater depth, the rooting depth of the crop and the texture of the soil essentially affect the contribution. Usually, areas where groundwater tables are very shallow are considered. Areas currently affected by shallow water table (i.e. average groundwater level within 3m) have been delineated in Chapter 5. There is likely some groundwater contribution at certain months of the growing season when the level is very close to the surface (< 1 to 1.5 m).

For practical purposes, the net irrigation water requirement in this study has been calculated by subtracting the estimated effective rainfall from calculated cotton water requirement without taking into account the groundwater contribution and residual soil moisture. Figure 4.7 portrays seasonal CWR and NIR for areas planted in mm/d. Similar to effective rainfall, monthly estimates of ETo is distributed over the entire year using polynomial curve fitting. The detailed calculation on 10-days basis is presented in Table 4.3; the NIR for the season is estimated as 71cm.

It is generally recognized that salts in soil or water reduce water availability to the crop to such extent that yield is affected. Therefore, leaching of accumulated salts from the rooting

depth before the salt concentration exceeds the tolerance of the plant is necessary. This is done by applying additional water than that needed by the crop during the growing season.

The minimum leaching requirement can be calculated as follows (Ayers and Westcot, 1985):

$$LR = \frac{\text{…….ECw……}}{5\ ECe - ECw}$$

Where,

LR = Minimum leaching requirements (mm)

ECw = Salinity of the applied irrigation water (dS/m)

ECe = Average soil salinity tolerated by the crop as measured on soil saturation extract (dS/m)

The salinity of the Awash river varies seasonally as well as spatially in the reach between Melka Sadi and AIS outfall near Asoba (see Chapter 6). With a value of 0.4 dS/m considered as average and an ECe value of 7.7 dS/m taken from Ayers and Westcot (1985) for 100% yield potential, the minimum requirement calculated is some 0.01. This should be considered barely enough as salts in Amibara accumulate on the surface during the fallow (non-cropping) period from shallow saline groundwater (see Chapter 7 for current soil salinity distributions as well as check considered pre-irrigations when dealing with irrigation scheduling in the following discussions).

The gross irrigation requirement, on the other hand, takes into account the leaching requirement and project or application efficiency and is related to the net irrigation requirement by the following equation:

$$GIR = \frac{\text{…….NIR…..}}{(1\text{-}LR)\ Ep/a}$$

Where,

GIR = Gross irrigation requirement (mm)

NIR = Net Irrigation requirement (mm)

LR = Leaching requirements

Ep/a**=** Project or application efficiency (%)

The design project efficiency (Ep) considered in the water management manual (Halcrow, 1983) is 50%. The GIR estimated for the season at this design project efficiency is some 143.4cm. The calculated water supply in l/s/ha assuming continuous supply is shown in Table 4.3, providing the irrigation water needed at project headworks (average value 0.78 l/s/ha). With calculated project efficiency (Ep) of 45% (see section 4.5.3), the GIR is then

about 16cm. All these estimations do not include pre-irrigations for proper leaching and cultural practices.

Table 4.3 Irrigation Water Requirement for Cotton (mm/period)

Crop: Cotton
Block # : [All blocks]
Planting Date = April 16
Calculation Time Step = 10 Day(s)
Irrigation Efficiency = 50% for water supply (WS) calculation

Date	ETo (mm/p)	Area (%)	Crop Kc	Etcotton (mm/p)	Pt (mm/p)	Pe (mm/p)	NIR (mm/p)	WS (l/s/ha)
16/4	59.09	15	0.06	3.55	1.16	1.15	2.4	0.06
26/4	60.27	35	0.14	8.44	1.4	1.4	7.04	0.16
6/5	61.27	55	0.24	14.56	0	0	14.56	0.34
16/5	62.06	75	0.38	23.75	0	0	23.75	0.55
26/5	62.62	95	0.58	36.17	0	0	36.17	0.84
5/6	62.95	100	0.75	46.9	0	0	46.9	1.09
15/6	63.03	100	0.89	56.41	0	0	56.41	1.31
25/6	62.87	100	1.03	64.59	10.05	8.73	55.86	1.29
5/7	62.46	100	1.11	69.49	24.46	20.93	48.56	1.12
15/7	61.83	100	1.15	70.95	31.91	27.17	43.78	1.01
25/7	60.98	100	1.15	70.13	33.84	28.78	41.35	0.96
4/8	59.94	100	1.15	68.84	31.71	27.04	41.8	0.97
14/8	58.74	100	1.13	66.52	26.88	23.13	43.39	1.00
24/8	57.40	100	1.10	62.94	20.59	18.08	44.86	1.04
3/9	55.96	100	1.04	58.24	13.95	12.72	45.52	1.05
13/9	54.46	100	0.96	52.54	7.84	7.61	44.92	1.04
23/9	52.93	95	0.84	44.43	2.77	2.77	41.66	0.96
3/10	51.42	75	0.63	32.16	0.08	0.08	32.08	0.74
13/10	49.96	55	0.43	21.55	0	0	21.55	0.50
23/10	48.60	35	0.26	12.5	0	0	12.5	0.29
2/11	47.36	15	0.10	4.89	0	0	4.89	0.11
Total	1216.19			889.55	206.64	179.6	709.96	[0.78]

Scheduling

In addition to the crop and soil data specified in previous sections, the model CropWat requires rooting depth, depletion coefficient (p) and yield response factor (Ky) data for practical irrigation scheduling.

Measured rooting depth data are available for cotton grown in the study and other areas. With rooting depth of about 0.1 to 0.3 m at the initial stage, it appears that the measured

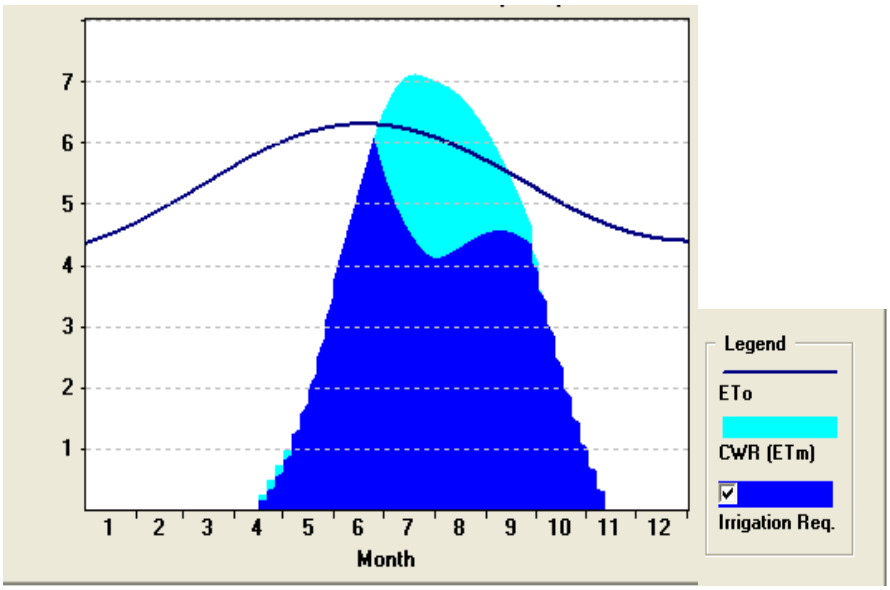
rooting depth of cotton in Amibara can attain 1.27m at late stage. It extends to over a depth of 1.4m in some areas.

Depletion coefficient (*p*) is fraction of the available water permitting unrestricted evapotranspiration and/or optimal crop growth (Doorenbos and Pruitt, 1992). Values of *p* for cotton at initial, mid and late-season stages considered 0.6, 0.55 and 0.85 respectively.

The yield response factor (Ky) expresses the response of yield to water supply quantitatively by relating relative yield decrease to relative evapotranspiration deficit. Ky values taken from Doorenbos and Kassam (1979) and updated CropWat model data for cotton are 0.2, 0.4, 0.5 and 0.25 for initial, crop development, mid and late-season stages respectively (total growing period ky = 0.85). Cotton is known to be relatively sensitive to water deficits during flowering and boll formation; therefore care should be taken if yields are to be maximized. Calculated yield loss should only be considered as a guide.

It is suggested that adequate water be available in the soil at the time of sowing. Stored soil water from “belg” rainfall events may be sufficient for some fields planted in April. The month May being relatively drier, there may not be adequate stored soil water, indicating the necessity of pre-irrigation. Subsequent irrigations at least need to water effectively the upper part of the root zone to about 75 to 100cm.

Figure 4.8 Graph of Seasonal Crop Water Requirements and Net Irrigation Requirements (mm/d)



Irrigation scheduling involves determination of application timing (interval) and depth (amount). Two irrigation water scheduling options (scenarios) have been taken into consideration with the following defined criteria:

- ***Scenario 1:*** Optimal irrigation criteria permit irrigation when 100% of readily soil moisture depletion occurs and refilling to 100% of readily available soil moisture to calculate irrigation interval (days) and depth (mm) respectively. Staggered planting date in the cropping pattern means irrigation scheduling is calculated for each block. This option resulted in 5 irrigations with depths varying from 60 to 67cm. Figure 4.9a shows irrigation schedule interval for a block sown in May 1 assuming negligible stored soil moisture at the beginning. Without taking into account application efficiency, the net irrigation requirement calculated is 599 mm (say 60cm) with depths of 46/112.6/144.4/140.9/155.1mm at 0/36/22/31/35 days interval. Irrigation is terminated 123 days after planting and yield reduction calculated is only 0.2%.
- ***Scenario 2:*** Irrigate by applying a depth of 12cm when 100% of readily soil moisture depletion occurs is another option with similar timing calculation but fixed depth. This resulted into six to seven irrigations with net depths of 600 – 720mm for staggered cotton planting blocks. Figure 4.9b is a scheduling graph for cotton planted on the 16th of May assuming negligible stored soil moisture at the beginning. With 12cm depths irrigated at 0/35/29/33/27 days interval the net application would be 60cm. Calculated yield reduction is only 0.2%. As it can be seen the figure, part of the first irrigation is shown as lost irrigation. Certain portion of this lost amount percolates below the root zone, which is to some extent useful for leaching of salts.

Making leaching water available before and immediately after planting is important as it helps to remove salts accumulated during the fallow season either from high water table of a saline groundwater or irrigation water salt build-up. It helps to avoid inhibition or delayed germination and early seedling growth. As it will be discussed in Chapter 7, certain parts of AIS soils are saline with ECe greater than 4dS/cm as sampled during the non-cropping period. Apart from leaching, pre-irrigations may be important for cultural practices. Nonetheless, Kiremt rainfall may be sufficient to leach accumulated salts from the soil. Therefore, some 220mm of pre-irrigation may be required in addition to the scheduled amounts above. Equally important when dealing with leaching requirements and salinity management is adequate drainage. Otherwise long-term salinity control could be difficult.

There are a number of suggested irrigation schedules for cotton grown in the study area. Kandiah (1982) suggested three irrigation regimes: i) once in two weeks with 75mm; ii) once in three weeks with 125mm; iii) a total of eight irrigations with depths 150/75/75/75/125/ 125/125/12 mm applied at 0/21/14/14/14/21/21/21 days interval by considering 70% application efficiency. Irrigation is terminated 126 days after planting. Experimental evidences indicated that although maximum yield is obtained at net application of 140cm than lesser amounts, optimum water use efficiency was achieved at net applications of 85 to 87.5 cm. Decreasing the number of irrigations from 8 to 5 with the latter depth also gave better yield.

The same author in collaboration with others came-up with a general schedule of a pre-irrigation followed by eight post-irrigations for cotton planted in Mid-May in Middle Awash (Haider and Kandiah 1988). Depths of 95/75/80/120/120/125/125/115mm at 21/13/13/ 15/15/18/18/21 days. Including 150mm pre-irrigation, the irrigation amount is some1005mm.

The water management manual prepared during Amibara Irrigation Project (AIP) by Halcrow (1983) adopted a partially fixed schedule and gave eight 130mm gross depth of applications at 14/28/21/14/14/14/21/21 days. Irrigation is terminated 135 days after planting. To this is added a pre-irrigation of 28.6cm depth, to be applied two weeks before the first day of irrigation.

A revised schedule was subsequently suggested by Halcrow (1985) in light of experience as the previous was producing periodic water-logging and excessive luxuriant growth with boll shedding. Two pre- and six post-planting irrigations scheduled at 20/10/20/20/40/30/30 with depths of 220/220/105/220/91/182/130/130mm for fine- and medium-textured soils. It was stated that the irrigation intervals have been rationalized in order to avoid overloading the canal system. Leaching of salts has also been scheduled by extra pre-irrigation.

It is evident from the above discussions that in addition to yield and water use efficiency, the evaluation of the scheduling needs analyzing the existing system design and practice as well as water availability. Although detailed analysis of the canal design parameters or manageable flow rates is not the scope of this study, some useful notes on the infrastructure of the Amibara schemes is forwarded in proceeding sub-sections.

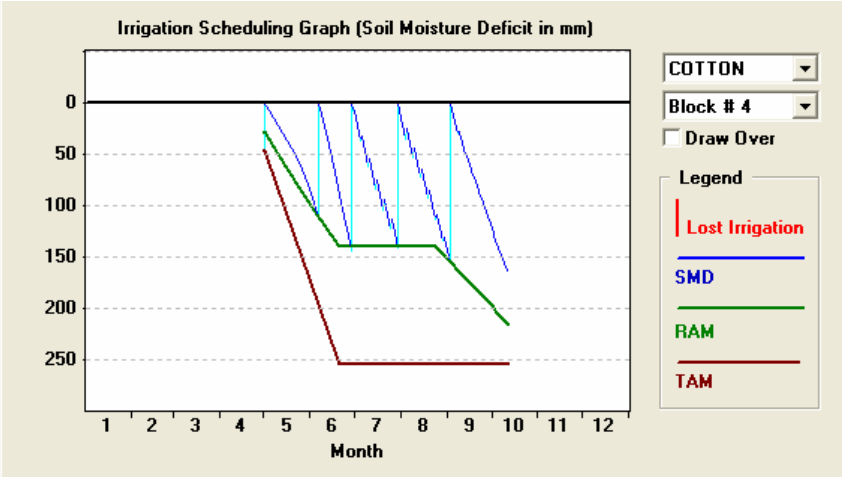
The total available moisture (TAM) taken in the scheduling exercises of the present Thesis study is 200mm, an average value considered for the heavy clayey and medium loamy soils. This indicates that in practice, the intervals may vary depending on the water holding

capacity of the soil units. Taking into account soil textures at field level helps to observe the likely effects of water-logging and water-stress that may be induced by the irrigation intervals.

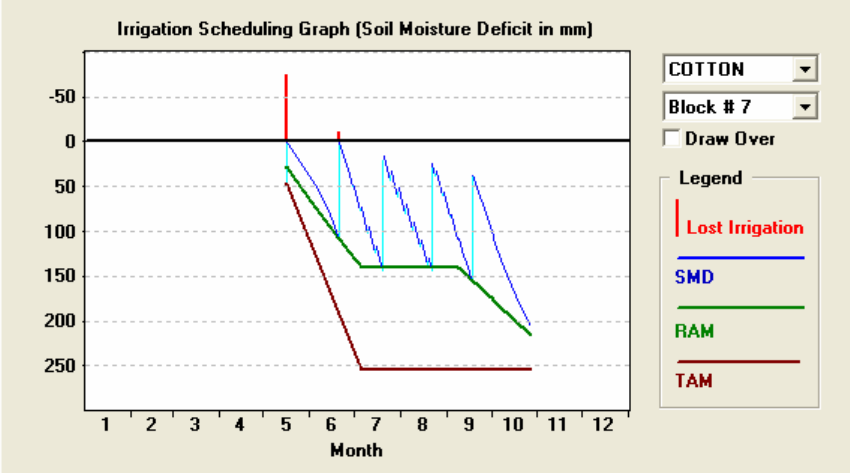
The model CropWat allows user-defined irrigation events plus the option to add adjustments (say rainfall events) to calculate soil moisture deficit (SMD). This can provide a flexible tool for monitoring soil moisture during the growing season. The present study is mainly dedicated in evaluating operational schedules with modeled scenarios semi-quantitatively. Therefore, discussions made in next section regarding scheduling will be on existing operational system and practiced schedule at farm scale.

Figure 4.9 Graphs of Irrigation Scheduling Scenarios

a) ***Scenario 1:*** Irrigate to return the soil to field capacity (i.e.100% RAM) when all the RAM is depleted



b) ***Scenario 2:*** Irrigate a fixed depth of 12cm when all the RAM is depleted



4.5 Evaluations of Surface Irrigation Practice and Water Management

4.5.1 Existing Infrastructure

The Amibara Irrigation Schemes are supplied with irrigation water from Awash by gravity diversion at Melka Sedi and by a number of pumps downstream of Melka Werer town. The former Melka Sadi banana, Melka Sadi- and Melka Werer-cotton farms, large portion of the former Amibara settlement farm and Werer Research Center are supplied from the gravity offtake system. The net area commanded by the gravity irrigation system is some 10,300 ha. Irrigation infrastructure map of AIS is presented in Figure 4.10.

The diversion weir at the Melka Sadi headworks is a rockfill structure founded on a blanket of graded filter material with an intake structure built on the right bank of the weir. The discharge at the head regulator is controlled by two vertical lifts gates installed in separate chambers with separate headstocks. Since its commissioning in 1980, the intake has been asserted as a regular source of worry being blocked by bedload, silt and debris from the Awash during the rainy season (Halcrow, 1983). This has been resulting in interruption of irrigation water supplies intermittently. Due to this problem and other related reasons, additional intake was constructed immediately upstream in 2003.

With a total length of some 26 km starting from the Melka Sadi head regulator, the main canal runs more or less NE-SW along the right side boundary of all schemes in Melka Sedi plain before reaching the link road which then changes its direction to nearly N-S direction in the Amibara plain extending upto the northern end of the former Amibara settlement farm (east of Sheleko town). It is provided with six primary check drops (CD1-CD6) fitted with overshot weir gates. Located few meters upstream of each primary check drop, there are ten primary offtakes (PO 1-10) on the main canal with other three (PO 11-13) situated at the tail end.

The primary offtakes on the main canal are provided with constant head orifices that help to measure the amount of delivered irrigation water to the former state MAADE, Werer Research Center and other private farms. The on-farm distribution system of the gravity schemes comprises a network of secondary, tertiary and field canals. The secondary canals are fed from the primary offtakes. Two exceptional primary offtakes directly feed tertiary canals. Though provided in some farms, duckbill weirs of varying crest length and gated secondary and field offtakes regulate and control the water distribution into the tertiary and field canals.

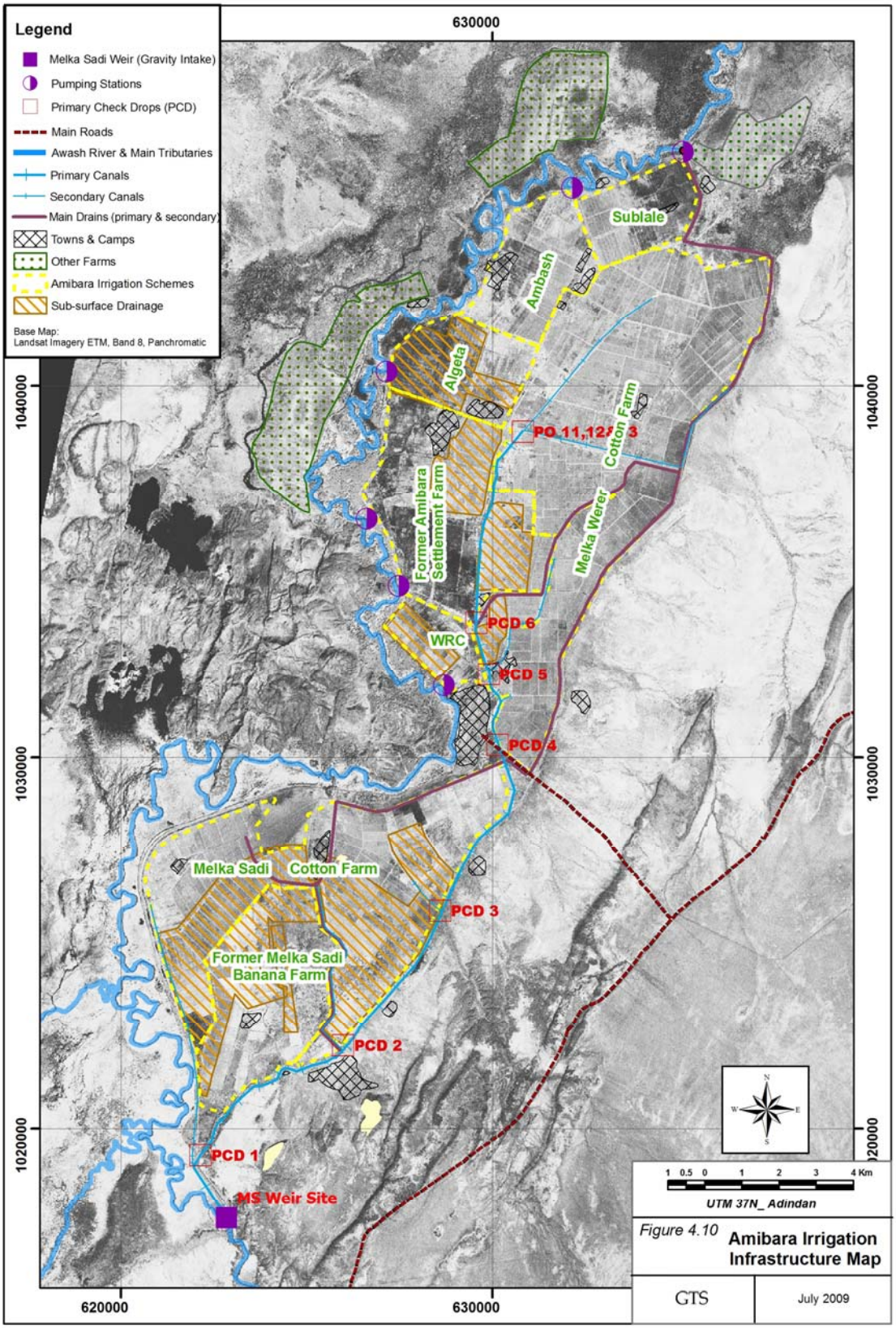
The north-western Algeta, Ambash and Sublale farms possess pumped irrigation system. It was learnt that in addition to the gravity supplies, some blocks of land within the former Amibara settlement farm and Werer Research Center are supplemented by pumping. From the seven pumping stations, a system of tertiary and field canals facilitates distribution of irrigation water.

With these supply systems, surface irrigation by furrows is the type of method employed in Amibara. Basin irrigation used to be practiced in the former Melka Sadi banana farm.

The western and eastern earthen embankments protect the Amibara Irrigation Schemes and a number of small towns and camps from flooding. The western flood dyke is 43 km long and runs along the right bank of Awash river from the Melka Sadi diversion weir up to the northern boundary of Sublale farm. The eastern catchment natural drains intercept part of storm runoff and discharge into Angelele area, north of the study area. The remaining runoff from the eastside is cutoff by the 32 km long eastern flood dyke which runs along the eastern boundary of the schemes from the Melka Sedi northwards to Asoba.

The Amibara irrigation schemes are provided with surface and sub-surface drainage facilities. The surface drainage network comprises the primary, secondary, tertiary and field drains that remove storm runoff and excess irrigation water from the various farms. The 29 km primary drain after collecting drainage flows from the subsidiary drains and rejection flows from canals finally discharges into the Awash river through a gravity flap-gated outfall. Prior to the construction of this outfall structure in 1983, the primary drain used to discharge into the Sublale-Asoba area.

The sub-surface drainage network consists of buried lateral and collector drains which are corrugated PVC pipes of varying size installed at an average depth of 1.7 and 2.5 meters respectively. The collector drains receive percolated water from the slotted laterals and outfall into the deep surface drains. In some cases the lateral drains directly outfall into deep open drains. An area of 3820 ha is served by the existing surface drainage facility (Figure 4.10). The total length of the collector and lateral drains is 1010 km as specified in MacDonald (1996). Concrete manholes have been installed on the collector drains for inspection and maintenance.

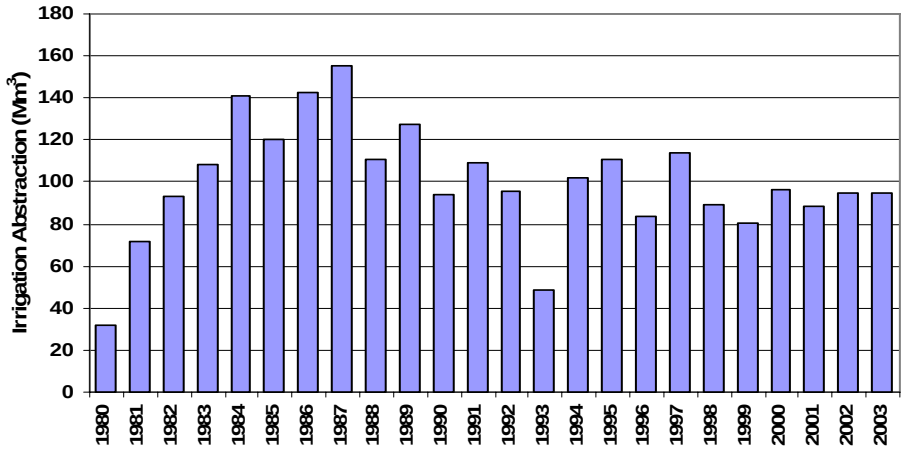

Legend
Melka Sadi Weir (Gravity Intake)
Pumping Stations
Primary Check Drops (PCD)
Main Roads
Awash River & Main Tributaries
Primary Canals
Secondary Canals
Main Drains (primary & secondary)
Towns & Camps
Other Farms
Amibara Irrigation Schemes
Sub-surface Drainage
Base Map:
Landsat Imagery ETM, Band 8, Panchromatic
630000
1040000
1030000
1020000
620000
Sublale
Ambash
Algeta
Cotton Farm
PCD 11,12
Former Amibara Settlement Farm
Melka Werer
PCD 6
WRC
PCD 5
PCD 4
Melka Sadi
Cotton Farm
PCD 3
Former Melka Sadi Banana Farm
PCD 2
PCD 1
MS Weir Site
N
W
E
S
1 0.5 0 1 2 3 4 Km
UTM 37N_ Adindan
Figure 4.10
Amibara Irrigation Infrastructure Map
GTS
July 2009

4.5.2 Irrigation Abstractions

Irrigation water abstracted from the Awash river is supplied to the gravity and pumping schemes. For the gravity system, primary offtakes from the main canal provide irrigation water to the various entities (farms). Figure 4.11 shows the extreme annual variations in irrigation amounts provided to the gravity-supplied schemes.

Regardless of irrigation efficiencies, it may generally be expected that the variations in irrigation abstractions largely depend on the amount of land planted or irrigated in different years. Figure 4.12 shows annual variations in net irrigated area supplied only by the gravity system. In effect, the non-linear regression between irrigation abstraction amounts and total land planted in Figure 4.13 reveals strong correlation, explaining about 80 % of the overall variation.

Figure 4.11 Recorded Irrigation Volumes Provided to Gravity-Supplied Schemes



The above situation highlights that taking simply an average of the irrigation abstractions would give less picture of the general water use without considering the net irrigated area annually. In view of this, the water use by the gravity supplied schemes has been calculated annually on a per hectare basis and is graphically portrayed in Figure 4.14. The temporal variations expressed in this way may partly help to show variations in irrigation efficiencies.

Despite the few anomalies, the linear trend dashed line fitted in the figure roughly shows a general trend in decreased water consumption per hectare. This may not necessarily indicate improving efficiencies. Nevertheless, the cropping pattern changes would have also had an influence to some extent. In this context, it is important to note the conversion of the Melka Sadi banana unit to cotton farm. The water demand of banana is relatively higher than cotton, influencing the general water consumption disproportionally.

Figure 4.12 Net Irrigated Area Supplied by the Gravity System

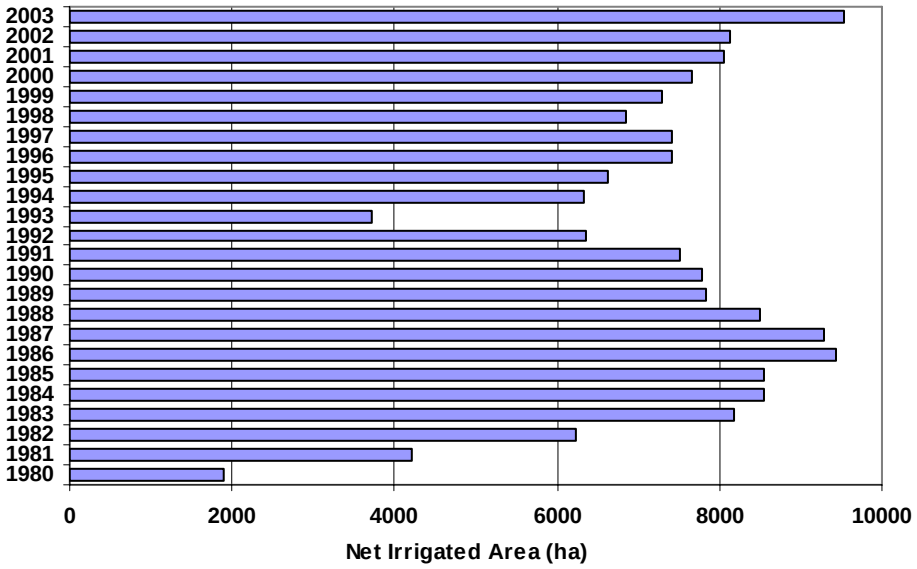
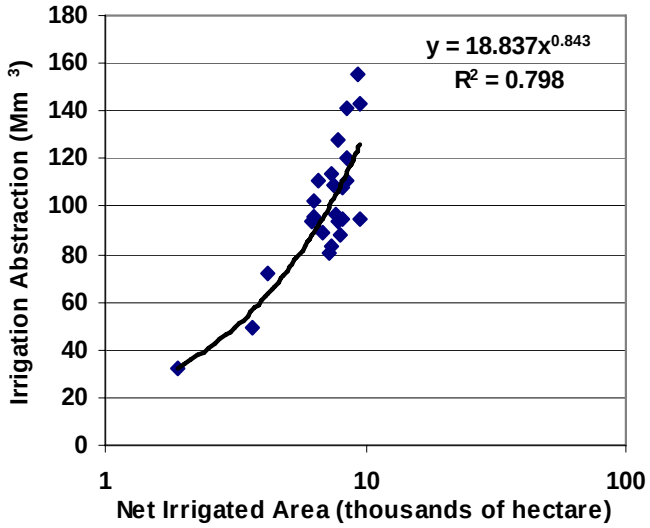


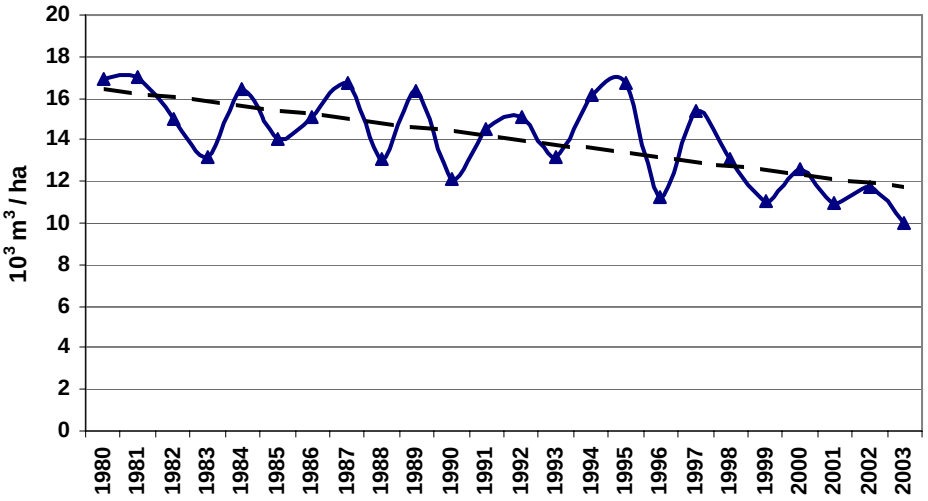
Figure 4.13 Correlation between Volume of Gravity-Supplied Water and Irrigated Area



Notwithstanding the above conditions, it is assumed that taking the mean would provide a reasonable indication of the likely water use on per hectare basis by the gravity supplied schemes. The mean annual irrigation water use is computed as 14.07 x 10^3 m^3/ha, which is equivalent to 1406.7mm.

In order to investigate practiced irrigation regimes/patterns, monthly averages of supplied irrigations to banana and cotton farms were analyzed. Banana being a perennial crop, irrigation is supplied through out the year. Figure 4.15a shows mean monthly variation supplied to the former Melka Sadi banana farm. Data covering years starting from 2001 are not included to calculate averages as the farm was converted to cotton since then.

Figure 4.14 Historical Water Use by the Gravity-Supplied Schemes



Cotton, on the other hand, is an annual crop. As it can be seen in the Figure 4.15 b&c (Melka Sadi and Melka Werer farms), the irrigation season is between April and November. Limited amount is supplied during the month of December. Part of April irrigation is considered as pre-planting irrigation despite the fact that some farms are known to exercise dry-planting.

There have been considerable variations in annual amounts of water supplied to the various farms. The graphs in Figure 4.16 show which years the major farms received large or lesser amounts of water. This has helped in studying patterns of groundwater level changes at farm-scale in Chapter 5. Some of the reasons for such variations, particularly due to land-use changes are also addressed.

4.5.3 Irrigation Efficiencies

Irrigation efficiency is one of the parameters used in evaluating the performance of irrigation projects. In surface irrigation systems, considerable water losses can occur during conveyance, distribution and application. With respect to Amibara gravity-supply system, the movement of water from Melka Sadi diversion through the main canal to the primary off-takes is conveyance. The movement of water through secondary and tertiary canals to field canals is distribution. Application is the movement of water from field canals through siphons to the crop land.

The AIS irrigation network being open unlined canals, there will be losses due to seepage and evaporation. Furthermore there are the direct rejections from canals into drains, which may be regarded as operational losses. Excessive application of water into fields will also result in deep percolation, tailwater (runoff) and unnecessary evaporation losses. Usually,

systematic analysis of these losses is made to determine conveyance, distributive and application efficiencies. The overall system efficiency (Ep) is the product of these three efficiencies.

Theoretically, the overall irrigation efficiency can be calculated as the ratio between the estimated irrigation requirements to the gross abstracted at diversion. In the above section, the estimated average water consumption for the gravity supplied schemes was based on measurements from primary off-takes on the main canal which essentially represents the distributed amount to the net irrigated lands. It does not take into account losses at the conveyance system as measurements at the head-works are not kept by the ABA.

Conveyance efficiency is the ratio between water received at the primary off-takes (inlet to block of fields) and that released at the project head-works (Melka Sadi intake). The conveyance losses include seepage and evaporation losses from the main canal plus direct rejections into drains. The first two losses can be fairly estimated using design parameters while it is difficult to measure operational losses without intensive measurements over a representative period of time.

Taking the computed net irrigation requirement as 71cm and the calculated mean annual irrigation water use as 14.1cm (1406.7mm) from preceding sections (4.4 & 4.5.2), the ratio calculated is about 50.5%. If a conveyance efficiency of 85% is assumed, then the overall system is calculated as 43% (say 40-45%).

The design project efficiency considered by Halcrow (1983) is 50% (conveyance and application efficiencies of 92% and 70% respectively). Shimelies Assefa (2004) measured field application efficiency at two selected farms, Melka Sadi and Melka Werer with an average value of 62.1 percent; measured conveyance efficiency in the secondary canal downstream of check drop 3 (CD3) with a calculated value of 88.1 percent; finally measured field canal efficiency to be 82.3 percent, to come up with a computed overall system efficiency of 45 percent. Tessema Woubneh (1986) (quoted in Shimelies Assefa, 2004) estimated 40-42% system efficiency range.

Figure 4.15 Mean Monthly Irrigation Volumes Supplied to Banana & Cotton Farms

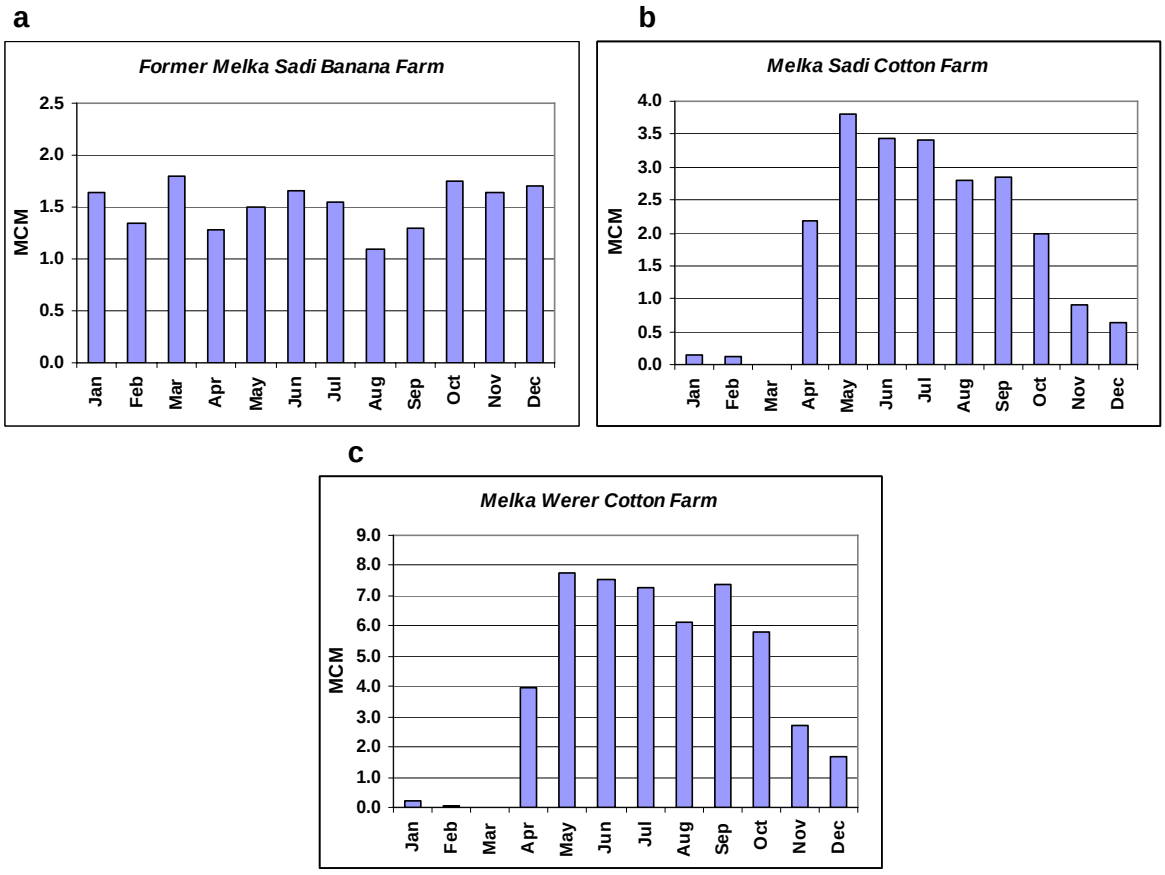
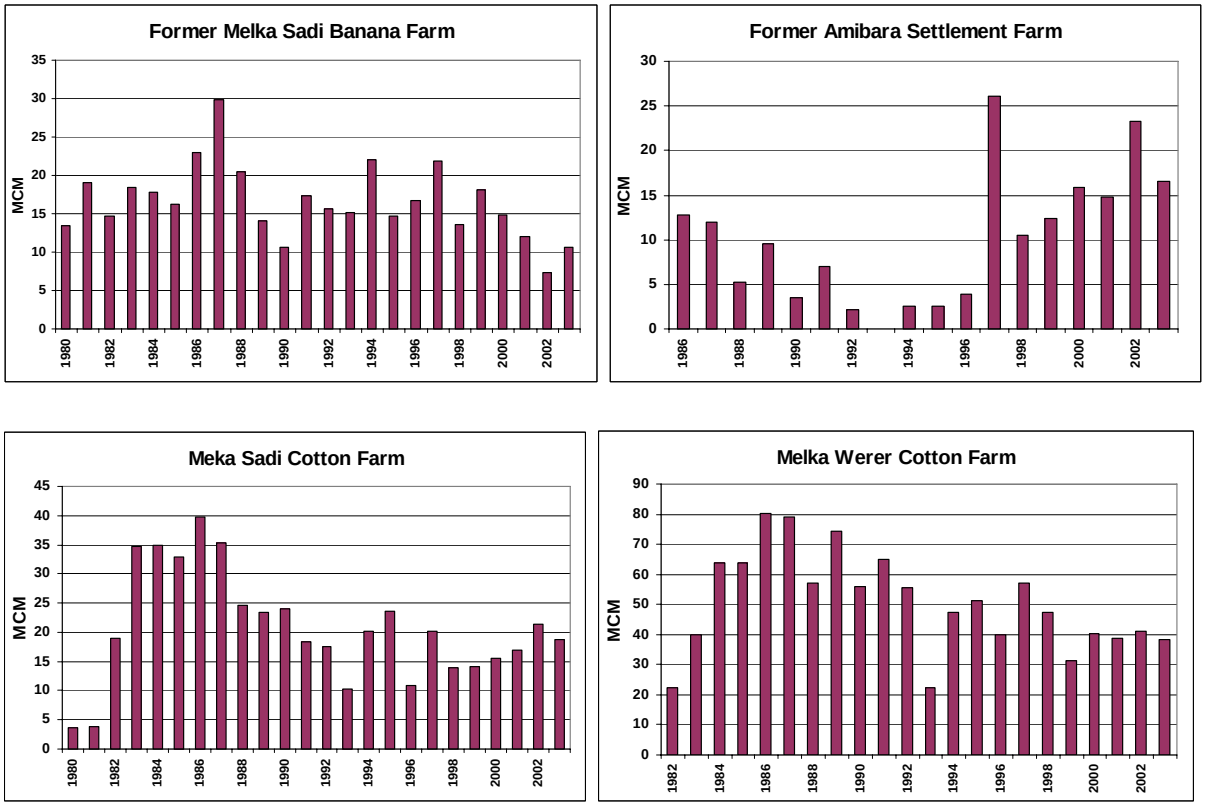


Figure 4.16 Annual Variations in Irrigations Supplied to Major Farms



4.5.4 Irrigation Practice and Water Management Challenges

A brief overview of the irrigation and drainage systems has been given under existing infrastructure (sub-section 4.5.1). This section discusses key issues related to inefficient water use in Amibara, particularly in relation to field practices and experiences learnt. It deals with system- and farm-level irrigation challenges. It particularly tries to investigate possible causes of irrigation water losses which may have contributed to rising groundwater table and salinity problems in Amibara. It makes use of valuable information that have been gathered during the field visits as well as from previous studies (Halcrow, 1983 & 1985; MacDonald, 1996) and system evaluation guidelines (Walker, 1989). It is meant to be integrated with the preceding sub-sections when evaluating the irrigation water management and general irrigation practice in Amibara.

Control structures and flow measurements

Irrigation water abstracted from the Awash river is provided to the gravity and pumping schemes. Farms should have adequate irrigation infrastructure, where canals and control structures have to be well designed and fairly implemented. It is quite mandatory that adequate water measurement facilities are provided if the amount of water to be managed is to be known.

The management of water in the field channels involves flow measurement, sediment and debris removal. The Melka Sadi diversion weir is located upstream the confluence of the Awash and Kesem rivers. The river bed is generally aggrading in this reach and sedimentation around the weir and intakes is a serious problem. The old intake is usually blocked by silt during the main rainy season and the scour sluice has stopped functioning long time ago. The new intake permits water only during high river stages.

There are few staff gauges on the river bank that can provide readings of the river stage at different flow periods. These could have been used to regularly calibrate the gates in order to determine the discharge into the main canal. However, the intake gates are fairly operated primarily to control the discharge into the main canal but measurements of the abstracted water at the headworks are not being made.

The main canal is designed for a design discharge of 13.5 m^3/s. The overshot weir gates of the six primary check drops are designed to pass the required downstream discharge while maintaining a constant upstream supply level (Halcrow, 1983). For the gravity supplied schemes, constant head orifice offtakes on the primary canal are used by Awash Basin Authority (ABA) to measure the amount supplied to the various entities and charge them

accordingly. Direct rejection flows from the main canal are allowed to pass over the four rejection spillways, provided upstream of the PCD.

Similarly, the on-farm distribution system from the primary offtakes to the field requires adequate flow regulating and control structures as well as flow measurement facilities. The Melka Sadi and Melka Werer cotton and the former Melka Sadi banana farms are provided with better infrastructure than most of the other farms, where the distribution network is reasonable. Moreover, the secondary and tertiary canals of these farms have also relatively better water measurement facilities than the others.

The secondary and tertiary offtakes within the Melka Sadi and Melka Werer cotton farms incorporate water measurement facilities. The former Melka sadi banana farm is provided with partial flumes at the secondary canal offtakes and calibrated sharp crested weir plates at the tertiary offtakes.

In contrast, there are only few partial flumes in the secondary canals within the former ASF. Insufficient flow measurement and regulating structures along the supply canals and lack of permanent control structures at tertiary and field canal level would likely make the irrigation distribution to be apparently inefficient.

Similarly, the control and measurement of irrigation water within the pumped schemes is not satisfactory. At present, water meters at the pumping stations are not either available or functional, thus no direct measurement of the amount of pumped water to the distribution system is made. With permanent control structures lacking, earth check dams are commonly used while siphoning is rather employed to transfer irrigation water from tertiary to field canals.

Drainage problems

The existing surface drainage system within the AIS incorporates deep open drains (primary and secondary drains) and lower-order drains. The total length of the deep open drains is about 50km (MacDonald, 1996).

In order to remove canal drainage flows and excess field runoff resulting from irrigation or storm runoff, properly designed adequate tertiary and in-field drains are required. The lower order drains within the former ASF and the pump schemes are inadequate as opposed to the existing fairly designed network of tertiary and field drains within most sub-blocks of Melka Sadi and Melka Werer cotton, and former Melka Sadi banana farms.

The existing primary drain outfall is fitted with flap gates that only allow drainage flows into the river and prevent river flood flowing back up the drain during high flow periods. Drainage flows during high river levels are let to pass over a rejection spill weir into Angelele area, north-east of the project area. During the field visit in August 2004, it was observed that water let to spread over the area east of the existing Asoba farm, forming silted and vegetated swamps that hindered effective drainage flows further downstream. This may to a certain extent affect the entire scheme's gravity drainage flow. The emergency spillweir is at times used to discharge drainage flows.

The buried sub-surface drainage requires proper and regular maintenance if adequate control of the groundwater table is to be achieved. The sub-surface drainage flow is effected by the existing deep surface drains. Therefore it requires rehabilitation of the primary and secondary canals to carry and effectively convey the subsurface flows, rejection flows and storm runoff.

As it will be discussed latter, the hydrogeological characteristics of the underlying alluvial sediments does not fully favor adequate and quick drainage to cope with the rising water table and associated salinity problems because of irrigation water percolation. In order to have effective adequate water-table control, it is necessary to increase the areal coverage of the farms currently served by subsurface drainage.

Field layout configurations

The field layouts of the Melka Sedi and Melka Werer cotton farms are elongated rectangles with longer furrows. The former Melka Sadi banana farm on the other hand has shorter furrows, being formerly small basins used for banana. On the other hand, the field layouts of the former ASF are less formal with large portions of the farm having irregularly-shaped fields. This may not favor efficient distribution and removal of drainage water. The pump schemes appear to be well, though land management may be different as developed by different investors. The layouts of the fields in some areas are rather cumbersome.

Land preparation

Surface irrigation requires proper land leveling. There exist noticeable micro-topography variations in the various farms. Annual tillage operations in preparation for cotton planting include ploughing, harrowing, smoothing and ridging. In avoiding variations in micro-topography, particular attention need be given to ploughing and land smoothing. It was understood that limited corrections are made to the ridges after pre-irrigation. However, operation of reforming the ridges not only needs to target control of weeds but also need to

mark depressions and other variations along the furrows for application uniformity. Depressions filled with water are potential sources of recharge due to deep percolation. Uncontrolled irrigations during night time flood fields filling depressions and adjacent areas.

Siltation of canals

Siltation of the canals is one of the major problems in Amibara. The canals are unable to deliver the necessary amount of water as their capacity is decreased due to siltation. Annual de-silting operations are carried out by the Awash Basin Authority albeit being restricted to the main canal. Minimal maintenance of the secondary and tertiary canals is performed by the farm owners.

Recent estimates of annually dredged silt from the primary canal for the years 2003/04 and 2004/05 by ABA are in the order of 102.5 and 219.7 thousand cubic meters respectively. Huge piles of excavated material have accumulated along the main canal.

The standard flow measurement curves will be affected if timely maintenance is not effected. After de-silting operation, it is unlikely that the original shapes of the canals are restored. Unless calibrations of inlet structures are regularly updated, it is possible that a greater or lesser amount of water is supplied as compared to ordered amount.

According to MacDonald (1996), the total annual volume of silt to be removed from the open drains is in the order of 75 x 10^3 m^3. During the field visits between 2003 and 2004, the drainage canals were observed on many occasions carrying still drainage water, which is clearly due to maintenance problems. Annual siltation and weed growth on the ditches destruct effective conveyance of drainage flows. This results in longer time and high level of drain water retention in the drainage canals. If the bed levels are not kept within the required slope ranges, it may affect the gravity drainage flow of the respective blocks.

Water distribution problems

Requests for water to the Awash Basin Authority are made weekly by the irrigators. Depending on the location of the fields, water released from the intake is distributed to the head, mid and tail-end users at varying times. The distribution however is affected by a number of factors. Operational losses due to rejections can be management issues between the supplier and users. Water theft has also become a problem as illegal users breach irrigation structures and divert water. It has been understood that the existing gravity supplied schemes receive six to four irrigations per season, the latter frequency being received by the tail-end users.

CHAPTER FIVE

GROUNDWATER TABLE / LEVEL RISE

5.1 Introduction

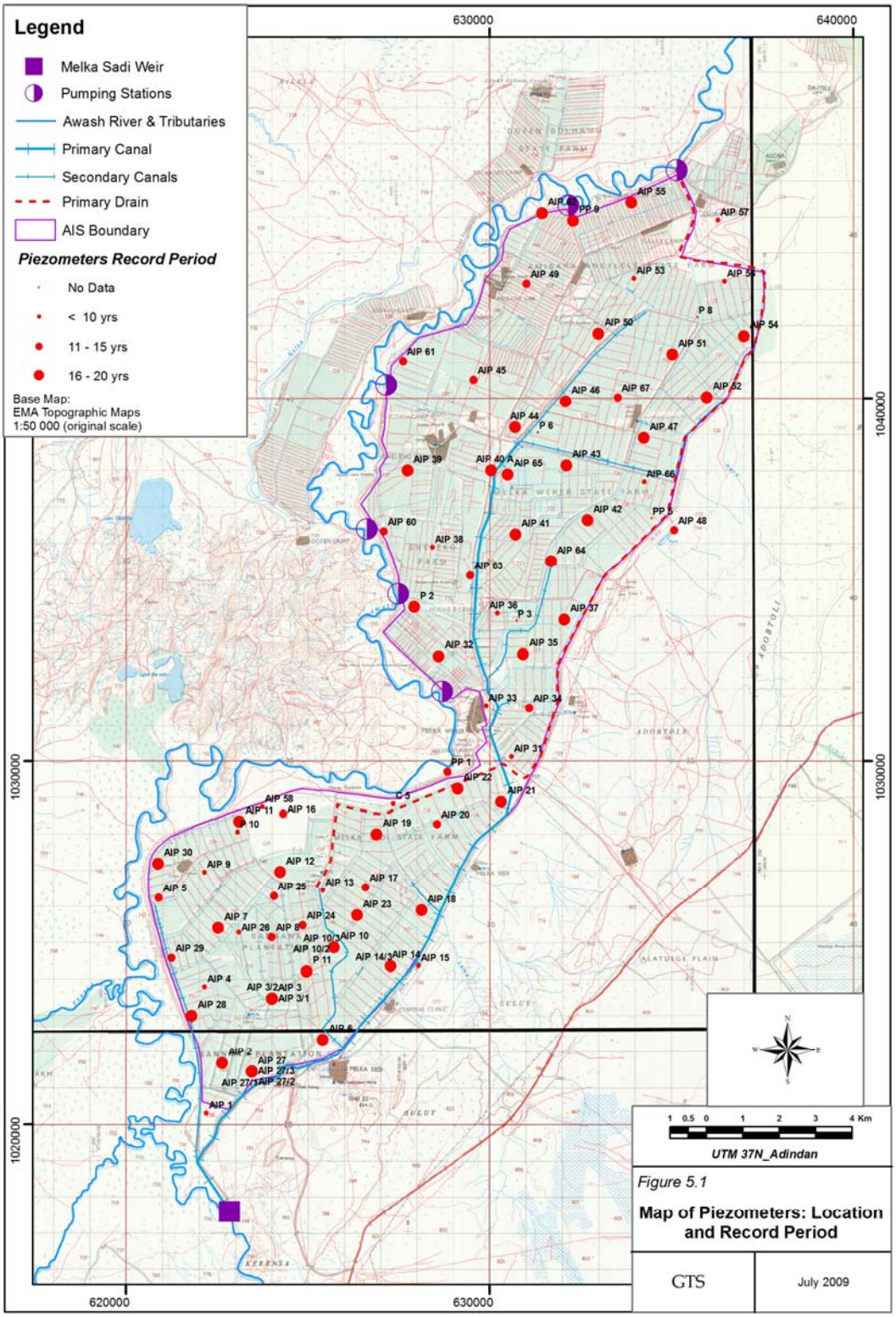
Excessive groundwater rising trends are usually observed in irrigated areas where intensive irrigation has been practiced for years and natural drainage is inadequate. A comprehensive hydrogeological investigation is required to investigate effects of irrigation on water and soil resources. This type of investigation in irrigated areas generally comprises hydrologic and hydro-chemical assessments that principally require piezometer data. Hydrologic assessments that involve systematic analyses of groundwater level data have been performed in this chapter to investigate rising groundwater levels in AIS. Specific tasks required to investigate farm-scale irrigation effects include: carrying out groundwater hydrographs analysis, producing depth to groundwater map, and performing groundwater flow analysis.

5.2 Data Availability

More than 90 piezometers (observation wells) have been installed in Amibara area and its immediate vicinity. Most of the piezometers were installed during Amibara Irrigation Project (AIP) in the early 80s, supervised by Halcrow and national contractors. The water levels and salinity (EC) of the AIP piezometers have since been monitored monthly, and these long term data were made available from the Awash Basin Agency (ABA). In addition, for few other piezometers installed by Italconsult, records of water level for the period 1971 to 1979 (reported in Halcrow, 1985) were also taken.

Furthermore, as part of this study, piezometer water levels were measured, in-situ field tests (EC, pH, T, Eh, etc.) were conducted during two field works (Nov 2003 and May 2004), and water samples were taken for chemical analyses.

Figure 5.1 shows the spatial distribution of the piezometers in Amibara Irrigation Schemes with their period of records indicated by graduated symbols. Most of the piezometers have more than 15 years of data.


Legend
Melka Sadi Weir
Pumping Stations
Awash River & Tributaries
Primary Canal
Secondary Canals
Primary Drain
AIS Boundary
Piezometers Record Period
No Data
< 10 yrs
11 - 15 yrs
16 - 20 yrs
Base Map:
EMA Topographic Maps
1:50 000 (original scale)
630000
640000
1040000
1030000
1020000
620000
1 0.5 0 1 2 3 4 Km
UTM 37N_Adindan
Figure 5.1
Map of Piezometers: Location and Record Period
GTS
July 2009

5.3 Groundwater Hydrograph Analysis

The main purposes of constructing groundwater hydrographs were:

- to investigate long term variation in groundwater levels, particularly to calculate rates of groundwater level rise
- to check groundwater level fluctuations in response to irrigation or seasonal rainfall conditions
- to spatially relate the results to land use and cropping pattern changes

Piezometers hydrographs categorized by farms are presented in Figure 5.2. It has been prepared by averaging monthly water level data of the piezometers to get mean annual levels.

As stated earlier, pumped irrigation in a relatively large area started in Amibara in the late 60s-early 70s. Although little information is available for the period 1971 to 1979, high groundwater levels (2m below ground level) were observed in the former Melka Sedi banana farm in the mid-70s, after only being irrigated for about five years. Piezometer P 11 records shows a rise from 5.7m in 1972 to 2m in 1976, i.e. an average rise of about a meter per year. In contrast, piezometers P 8 and P 5 (presented in Halcrow 1985), both located in Melka Werer farm, didn't show level variation during this period as the farm was not irrigated in the 70s.

Sustained trend of rising groundwater tables amplified rather spatially in the 80s in Melka Sadi and Melka Werer farms, following the start of gravity irrigation supply and subsequent increase in irrigated lands (see hydrographs in Figure 5.2a&b).

For example, groundwater level of AIP 43 (located in Melka Werer farm) was 11.20m in 1984 that reached 2.61m below surface in year 1990 within 7 years of irrigation; this gives an average rise of 1.2 m/yr. Likewise, water level of AIP 9 in Melka Sadi farm was 10.53m in 1980 that reached close to surface (1.97m) in 1990 within 11 years to give an average rate of rise of 0.8 m/yr. In general, rate of rise between 1980 and 1990 calculated for majority of the piezometers in Melka Sadi and Melka Werer cotton farms vary from 0.3 to over 1 m per year.

In the 90s such sustained groundwater level rises without interruption were observed only in the Melka Werer farm. Examples are piezometers 47, 51, 52 and 54 located in the north-eastern part of the Melka Werer farm (see Figure 5.1 & 5.2). This part is very far away from the Melka Sadi head works and receive modest amount of irrigation water from the

downstream reach of the main canal. With relatively gradual increase, calculated rate of rise range is 0.3 - 0.5 m/yr between 1990 and 2000.

It is important to note here that once the piezometer levels reach close to the surface, rate of rise decreases and annual average levels tend to stabilize. It can be seen in Figure 5.2 that majority of the piezometers stabilized but on different periods. For example, the groundwater levels in former Melka Sadi banana farm have already reached close to the surface in the 80s as irrigation has been practiced in this area long before the other gravity-supplied schemes. Groundwater levels reached close to surface in the 90s in the Melka Sadi and Melka Werer cotton farms

On the other hand, decreasing piezometer water levels were evident in the early 90s to mid 90s in some portions of virtually all farms. Examples include piezometers AIP 41 & 63 in the former Amibara settlement farm, piezometers 44 and 50 in the left canal bank downstream of the main canal (part of the Melka Werer farm) and other piezometers AIP 65 and AIP 46 in close proximity to the latter ones that showed considerable decrease in annual average water levels. Several other piezometers in the former Melka Sadi banana farm and Melka Sadi cotton farms as well as few piezometers in the north-western farms also showed similar decreasing trend during this period (see piezometers in Figure 5.2a,c&e).

Decreasing water levels for extended period of time (from mid 80s to late 90s) were observed in the former Amibara settlement farm (AIP 39 & 63). Piezometers P 2 and AIP 32 located in Werer Research Center farm showed a rising trend up to the mid 80s followed by decrease in levels up to the late 90s.

Close inspection of groundwater levels variation of some piezometers indicated that relative rise and decline of levels are influenced by the amount of irrigation water supplied to respective farms (Figure 4.16 of Chapter 4). Declining groundwater levels are attributed to transfer of portions of irrigable lands to the Afars as well as to salinity and shallow groundwater problems that together resulted in subsequent abandonment of the fields for some time. The likely effects of earthquake events on piezometers levels also need to be investigated as fissures can form to act as groundwater conduits. Particularly those piezometers with sharp level decline in the mid 80s need to be inspected.

While the above analysis have helped to recognize the long-term variations in groundwater levels, it is also important to study seasonal fluctuations. Accordingly, mean monthly averages were calculated for some selected piezometers. As it can be seen in Figure 5.3, the groundwater levels of the selected piezometers vary seasonally. The levels start rising in

May and begin to decline between October and November. This pattern tends to correspond to the cotton irrigation regime portrayed in Figure 4.16 b&c of Chapter 4. It is also influenced by the temporal variations of rainfall and stream flow discussed earlier in Chapter 3. PP1 is a piezometer close to mainstream Awash that have distinctly noticeable monthly average peaks in July and August.

Figure 5.2 Groundwater Hydrographs of Piezometers in Various Farms

5.2a Selected Piezometers in Melka Sadi Cotton Farm

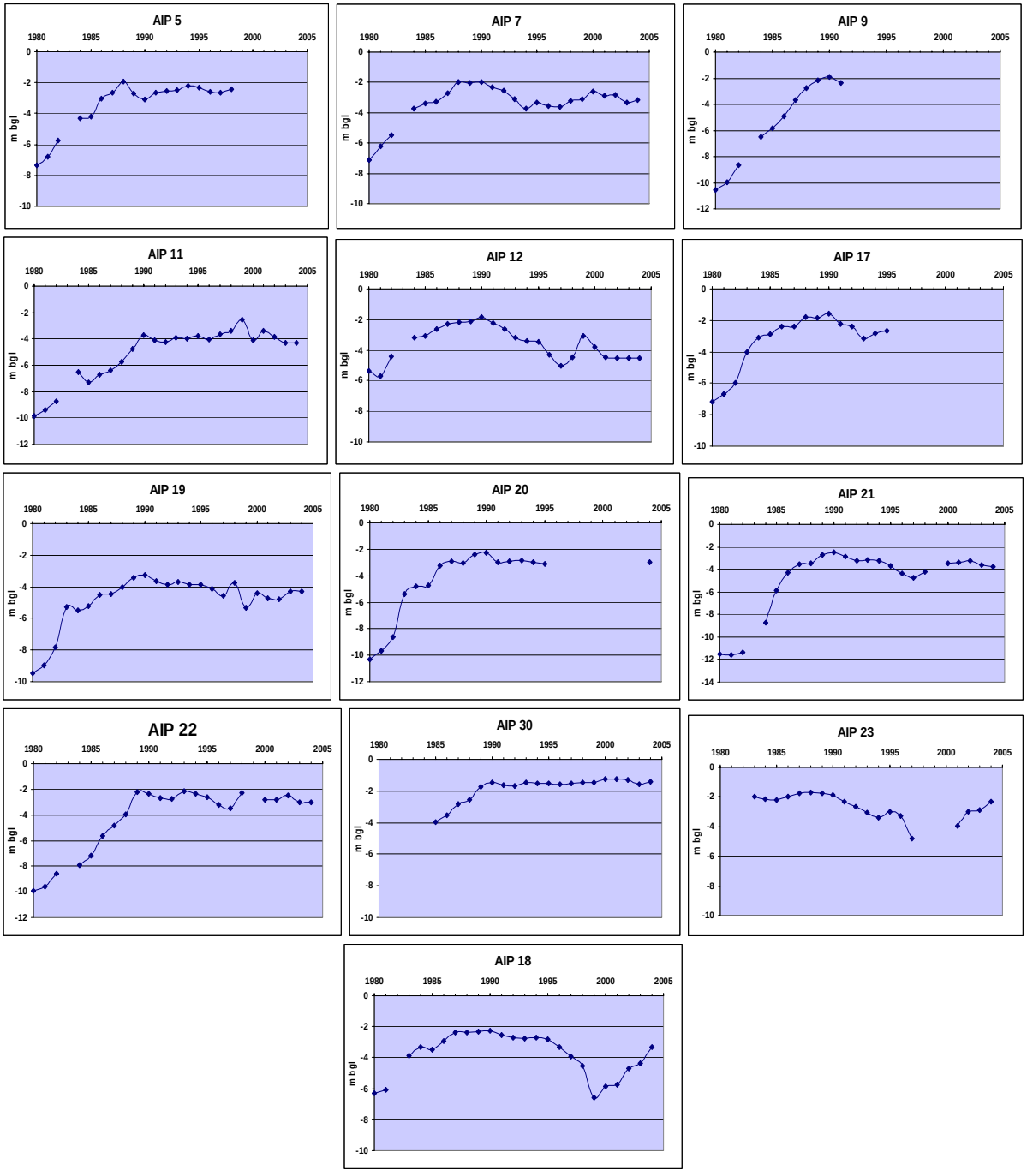


Figure5.2b Selected Piezometers in Melka Werer Cotton Farm

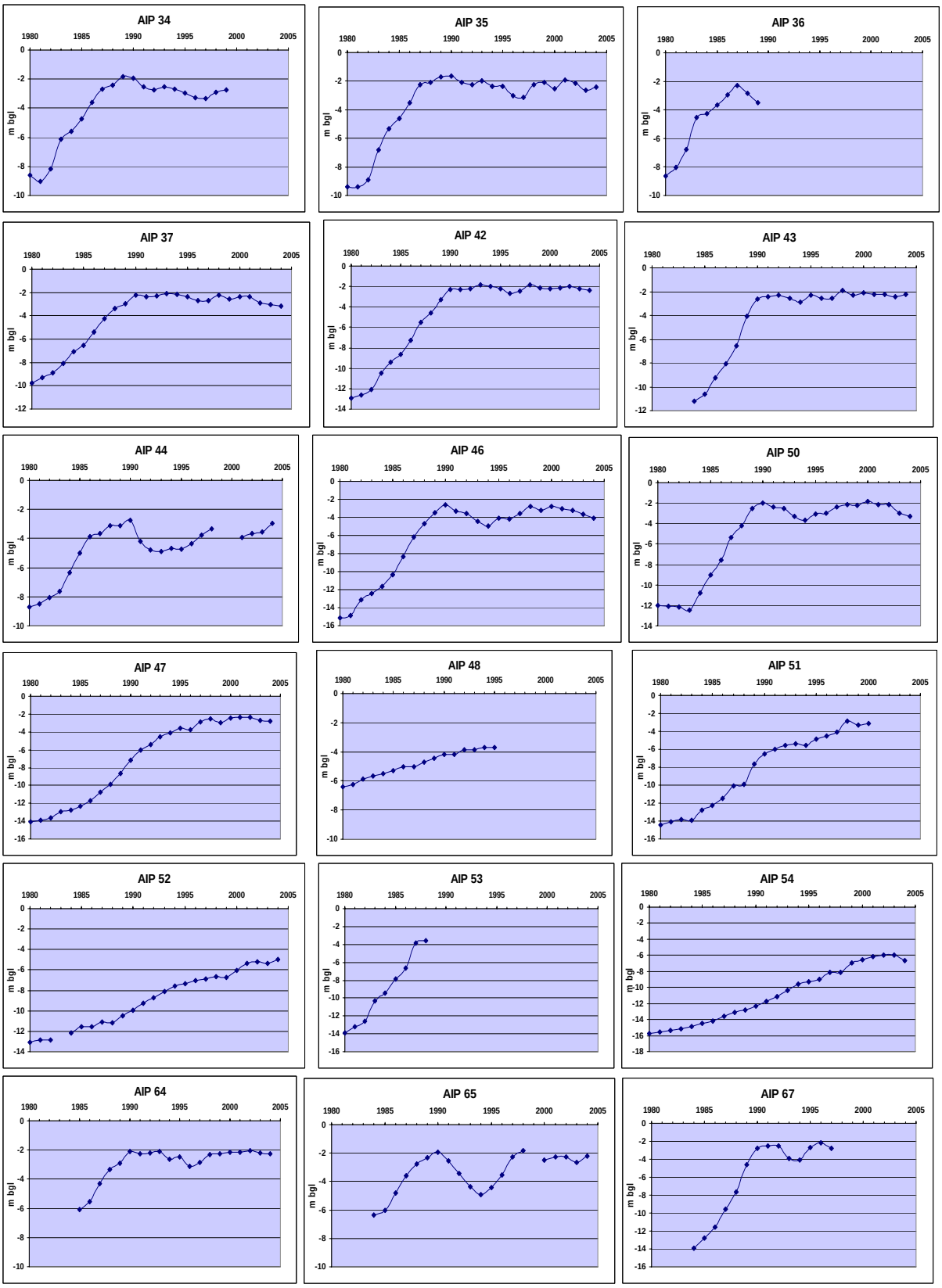


Figure5.2c Selected Piezometers in Former Melka Sedi Banana Farm

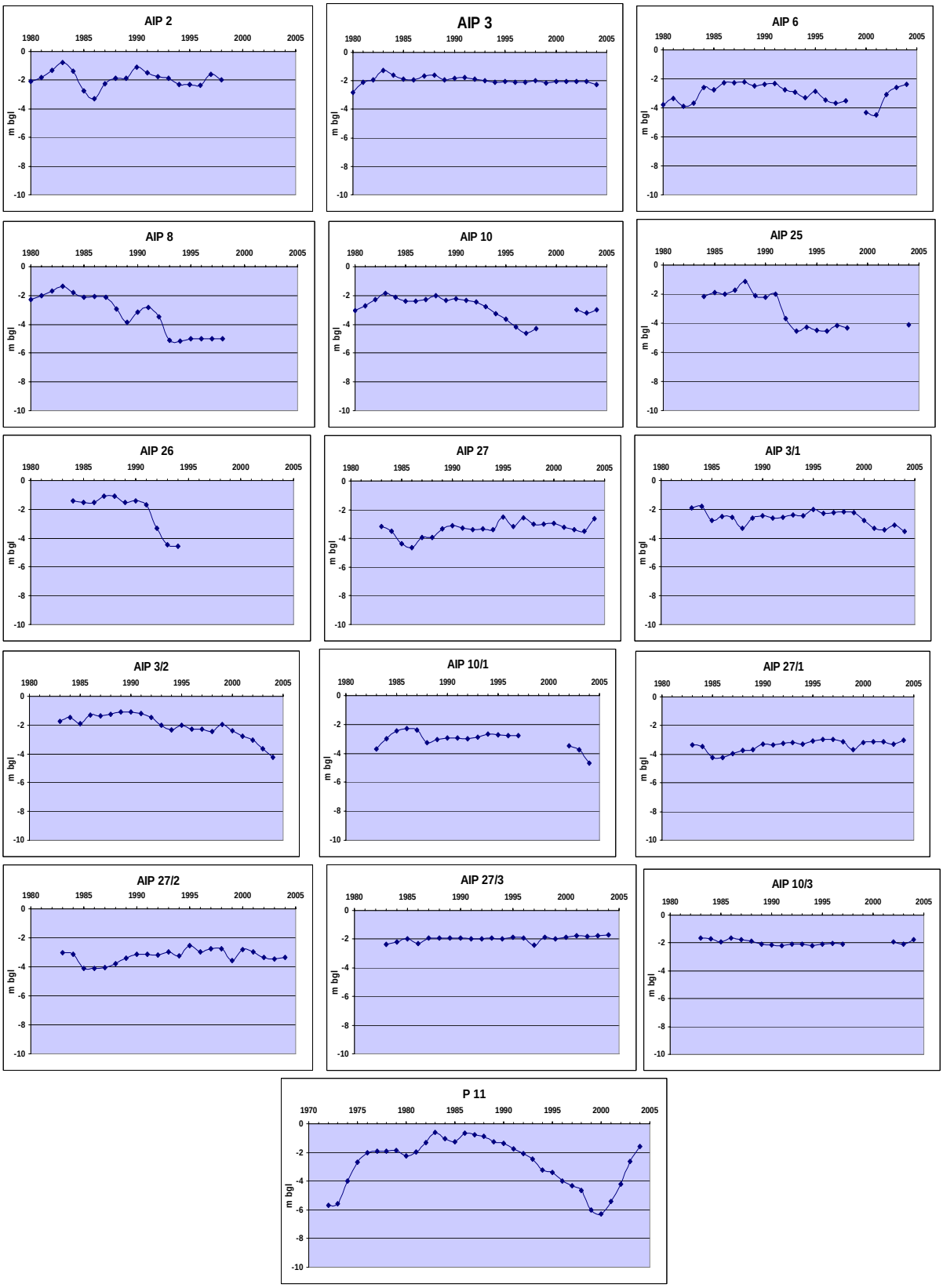


Figure5.2d Selected Piezometers in the Former Amibara Settlement Farm

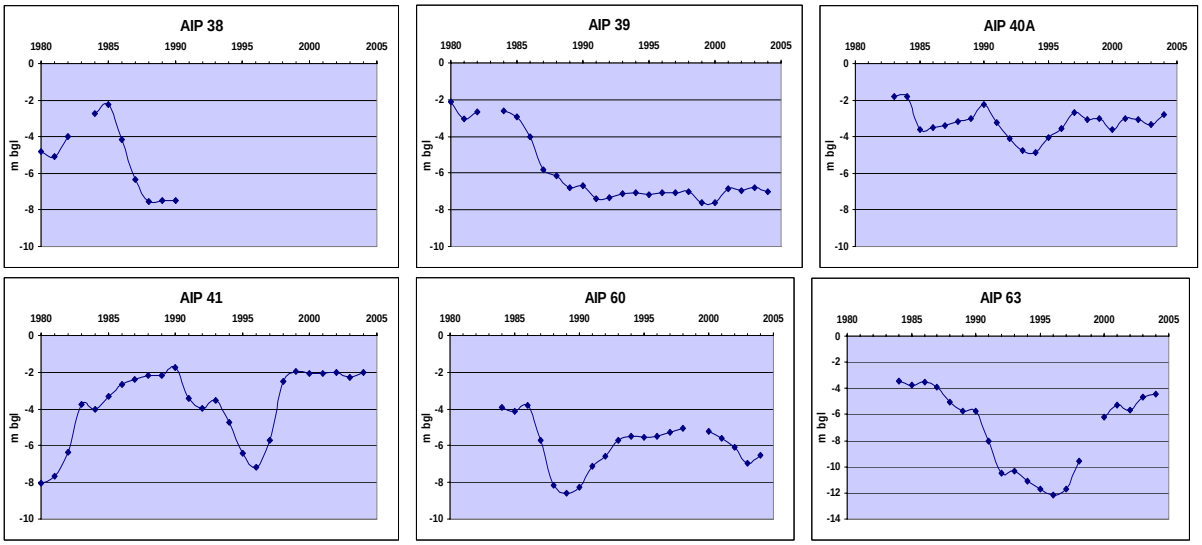


Figure5.2e Piezometers in the North-Western Farms (Algeta, Ambash and Sublale)

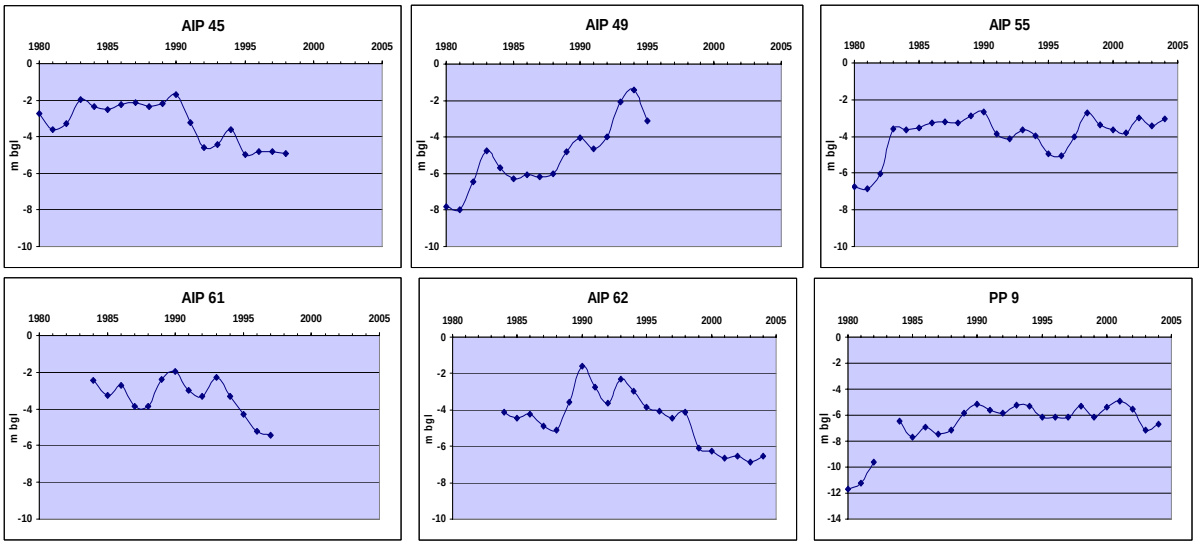


Figure 5.2f Piezometers in WRC – EARO farm

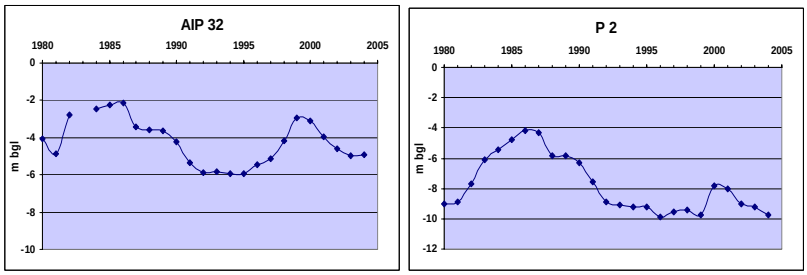
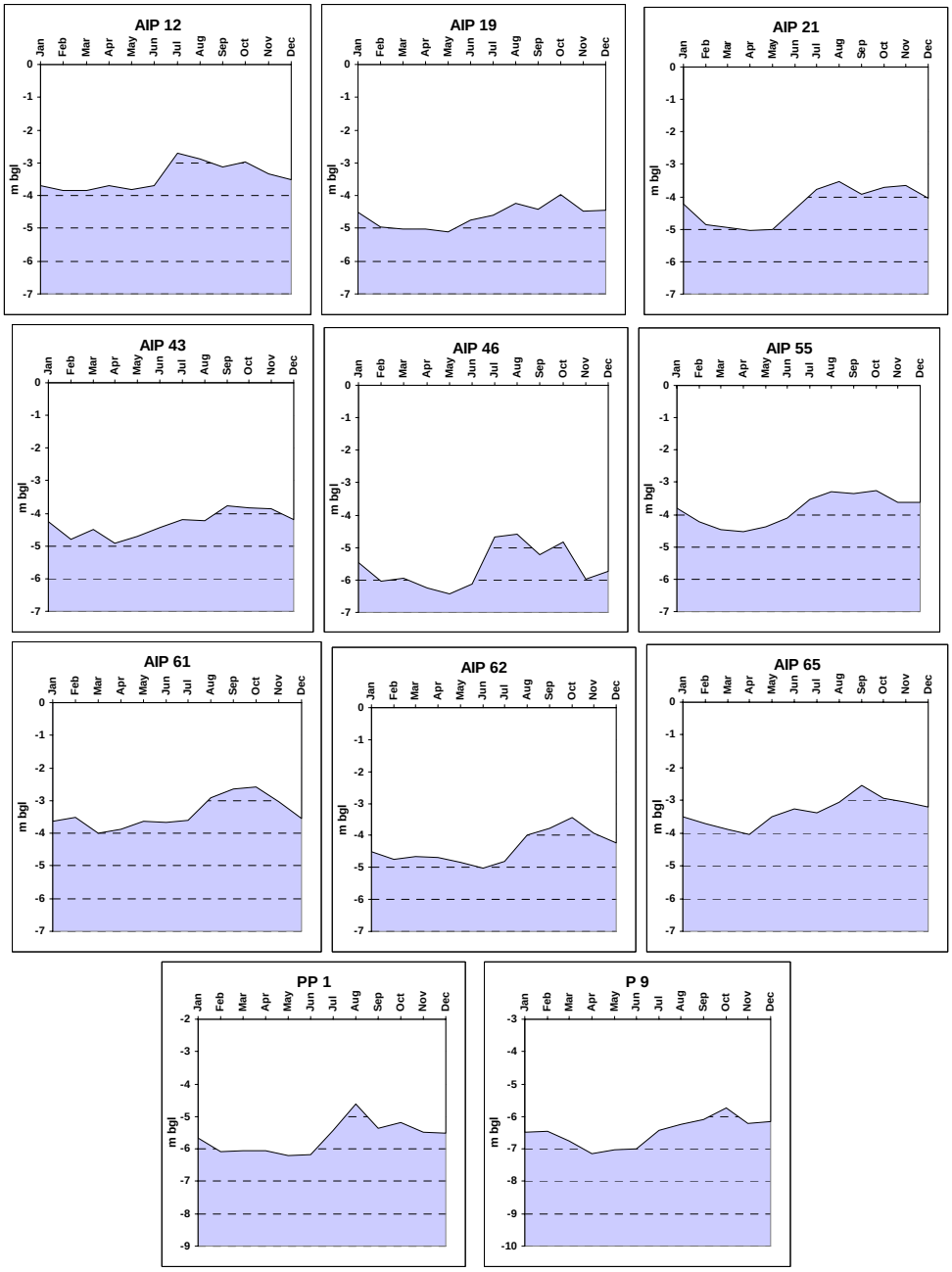


Figure 5.3 Selected Piezometers Showing Seasonal Variations in Groundwater Levels



5.4 Analysis of Groundwater Flow

One of the most powerful analytical tools for analysis of groundwater flow is construction of flownets – set of equipotential lines and flow lines (Freeze and Cherry, 1979). For practical reasons, two-dimensional (2D) flownets are usually prepared from piezometer data.

A groundwater contour map with inferred predominant local ground water flow directions is shown in Figure 5.4. In order to prepare this map, over 40 piezometers with recent data were selected and their monthly groundwater depth averages for the hydrologic year July 03 – June 04 calculated. Also incorporated are the field measurements conducted in Nov 03 and

May 04 as part of this study, together with other monthly readings taken by ABA. The difference between the piezometers' absolute ground elevations and groundwater depth averages were calculated, and these values were interpolated to create a GIS raster surface. Groundwater elevation contours (equipotential lines) of a meter interval were drawn from this interpolated surface and hydraulic gradients imaginarily drawn at right angles to these contours to help deduce important recent local groundwater flow conditions.

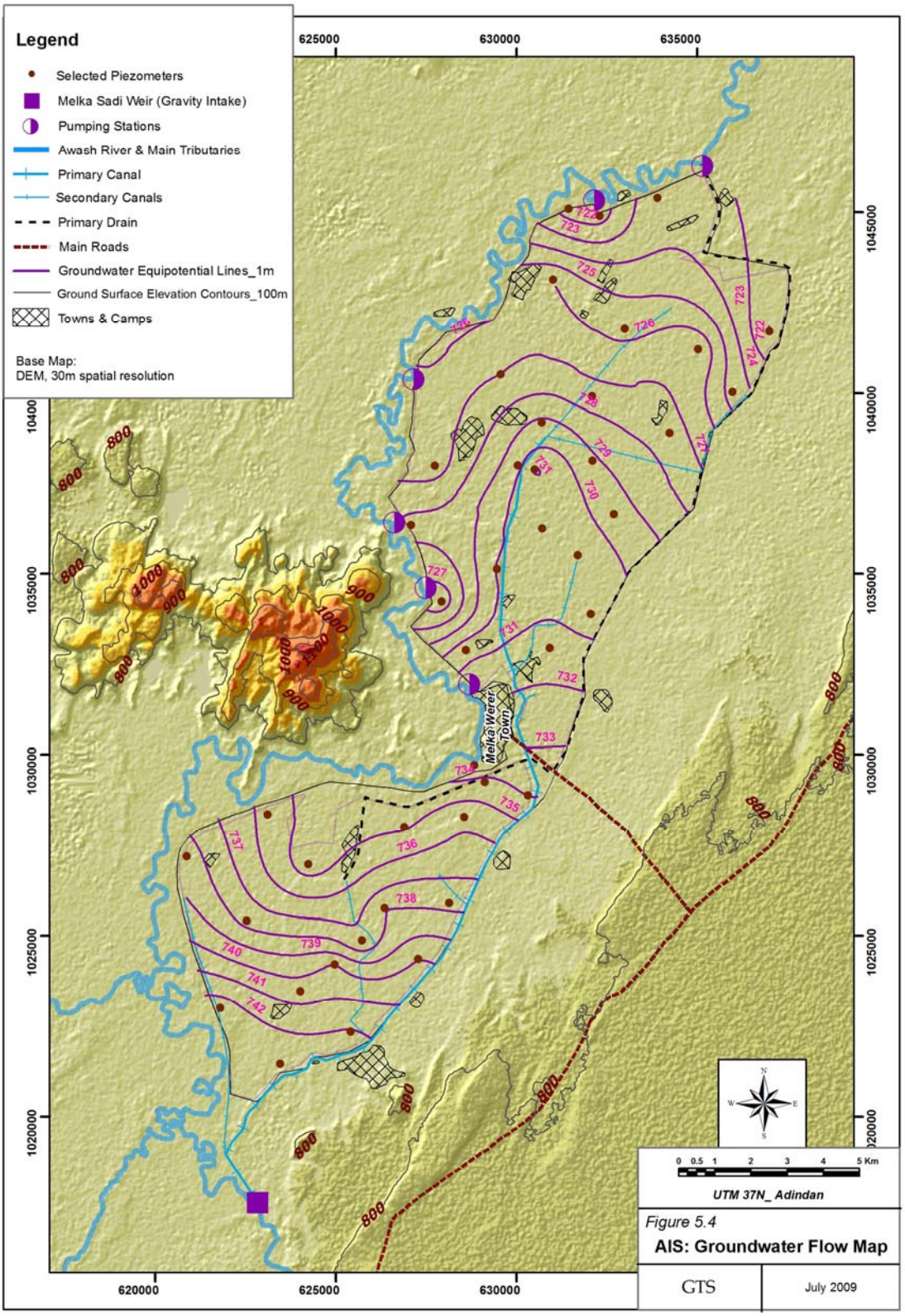
The following are some of the valuable information gathered from the groundwater elevation map:

- Surface water–groundwater interaction; potential sites where there is possible hydrologic transfer between river-groundwater and irrigation canal-groundwater.
- The hydraulic gradient or as indicative contour spacing of equipotential lines
- Groundwater flow conditions: comparison between the recent and the 80s.

In Figure 5.4, possible groundwater inflow to the Melka Sadi plain can be observed from the relatively elevated adjacent areas and the Awash river. It can also be seen that the groundwater has possible outlets to mainstream Awash in Melka Sadi area (upstream of Melka Werer town) and in Amibara areas (downstream of Melka Werer town). Notwithstanding these, it may generally be deduced that notable groundwater flow possibly occurs towards the north, from Melka Sadi area to Amibara plain (Melka Werer farm area) which may also flow further downstream to Angelele plain (Asoba farm area) following sub-regional conditions depicted in Halcrow (1989).

Furthermore, the effects of irrigation canals can also be observed. In Melka Sadi area, equipotential lines appear to be influenced by a major secondary canal - a gaining canal reach in the middle and a kind of losing reach near the canal end. Of major importance, the main canal downstream of Melka Werer is situated on relatively elevated ground in that equipotential lines to the left bank align along this canal while a groundwater mound with very low hydraulic gradient occurs on the right bank. In either case, it may be considered that the canal is losing water to adjacent groundwater acting as possible groundwater divide.

It is generally known that configurations of groundwater equipotential lines change with time. Comparisons were made between the current map and groundwater contour maps prepared by Haclcrow (1985) and Dereje Hailu et al. (1996) for groundwater conditions of the 80s. Referring to depth to groundwater in Melka Werer cotton farm area, the levels were relatively deeper in the 80s. As expected, relatively steeper hydraulic gradients (perpendicular to equipotential lines) could be observed in the maps of the above two studies.


Legend
Selected Piezometers
Melka Sadi Weir (Gravity Intake)
Pumping Stations
Awash River & Main Tributaries
Primary Canal
Secondary Canals
Primary Drain
Main Roads
Groundwater Equipotential Lines_1m
Ground Surface Elevation Contours_100m
Towns & Camps
Base Map:
DEM, 30m spatial resolution
Melka Wereri Town
625000
630000
635000
620000
1045000
1040000
1035000
1030000
1025000
1020000
10400
0 0.5 1 2 3 4 5 Km
UTM 37N_ Adindan
Figure 5.4
AIS: Groundwater Flow Map
GTS
July 2009

5.5 Depth to Groundwater Map

Figure 5.5 presents depth to groundwater map of AIS prepared from piezometers' groundwater level averages (July 03 - June 04 period). With suitable depth to groundwater classes chosen, their respective areas have been calculated and presented in Table 5.1.

Some of the points taken into consideration when demarcating the classes of depth to groundwater include seasonal changes in groundwater depth, long-term groundwater level changes and land-use dynamics, capillary movement of water and solute, root zone depth of cotton, evaporation reach, and existing and potential management measures with respect to drainage and salinity control (for example sub-surface drainage facilities).

Table 5.1 Classes of Depth to Groundwater

No.	Groundwater Depth Class	Description	*Area (ha)	% Area
1	GWD 1	Groundwater within 3m	5129.3	33.7
2	GWD 2	Groundwater depth between 3 - 4 m	7321.0	48.1
3	GWD 3	Groundwater depth between 4 - 5 m	1352.3	8.9
4	GWD 4	Groundwater below 5 m	1429.2	9.4
	Total		**15231.7**	**100.0**

Note: Depth refer to annual average depth;
Groundwater locally occur within a meter in some areas (especially very close to canals)
***** refers to gross area under investigation

GWD 1

As it can be seen in the map, the average groundwater level is generally shallow (less than 3m) in about one-third of AIS. Seasonally, water levels can reach the cotton root zone. This class includes considerable parts of the former Melka Sadi banana, Melka Sadi- and Melka Werer-cotton farms. Locally, the groundwater is encountered within a meter's depth; for example, in areas of perched water tables and in close proximity to canals.

Except in Melka Werer farm area, the groundwater has long been close to surface in the Melka Sadi plain. Referring to section 5.3, groundwater levels have already reached within the root zone in former Melka Sadi banana farm in the late 70s. With commencement of gravity supplies in the 80s, groundwater in most parts of Melka Sadi cotton farm have reached to an average depth of 3m in the late 80s. As it can be seen in Figure 4.10 (Chapter 4), some parts of these areas have already been provided with sub-surface drainage. In contrast, the groundwater have become within 3m in Melka Werer farm area in the 90s. This area still does not possess sub-surface drainage facility.

With such shallow water table prevailing in AIS, water and solute can rise into the active root zone by capillary action. Crops are likely to be affected by water-logging and secondary salinization. Leaching cannot be effective in areas with restricted drainage.

GWD 2

In nearly 50% of AIS, the average groundwater level is between 3 and 4m. Large parts of Melka Sadi cotton, Algeta and Ambash farms as well as northern part of Melka Werer cotton farms are included in this class. Occasionally, seasonal water levels can reach the cotton root zone in some areas. Similar to GWD 1, the groundwater is within a meter's depth locally in areas of perched water tables and in close proximity to canals.

When checking the long-term groundwater level changes and land-use dynamics, the groundwater in Algeta area used to be very close to surface even in the 80s. Algeta farm has been provided with sub-surface drainage facility since the early 90s. It is due to abandonment of the land for some period of time that resulted in decreased average water level in the area.

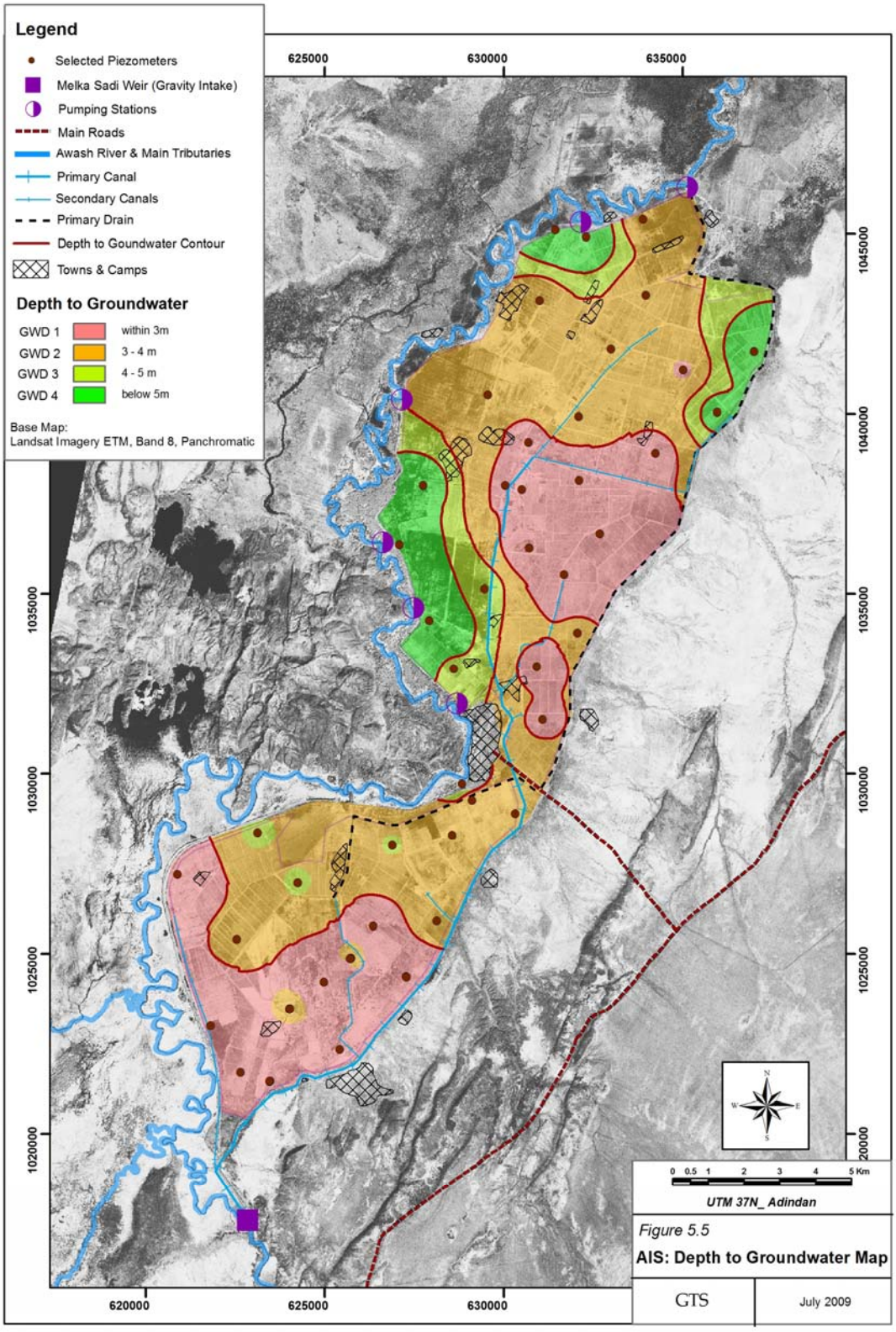
Nonetheless, sub-surface drainage facilities do not exist in much of this class. With the current irrigation activity and groundwater level rising trend in the area, the average groundwater will possibly be within 3m in a few years time. Thus, leaching alone may become inefficient unless water levels are kept low by providing adequate drainage soon.

GWD 3

Limited areas accounting to about 9% of AIS have been delineated as GWD 3 (average groundwater levels between 4 and 5m). Some parts of the former Amibara settlement farm, Werer Research Center are included in this class. The groundwater in parts of these areas used to be very shallow (average depth 2m) in the mid 80s. Unlike these areas, groundwater levels didn't reach 5m until the late 90s in limited north-eastern portion of the Melka Werer cotton farm.

GWD 4

Average groundwater levels below 5m occur in areas close to the Awash river and adjacent to GWD 3 in the former Amibara settlement and Werer Research Center farms. Also included is the extreme north-eastern part of Melka Werer cotton farm, considered as one of the possible groundwater outlets of AIS (see section 5.4).


Legend
Selected Piezometers
Melka Sadi Weir (Gravity Intake)
Pumping Stations
Main Roads
Awash River & Main Tributaries
Primary Canal
Secondary Canals
Primary Drain
Depth to Goundwater Contour
Towns & Camps
Depth to Groundwater
GWD 1 within 3m
GWD 2 3 - 4 m
GWD 3 4 - 5 m
GWD 4 below 5m
Base Map:
Landsat Imagery ETM, Band 8, Panchromatic
625000
630000
635000
1045000
1040000
1035000
1030000
1025000
1020000
620000
0 0.5 1 2 3 4 5 Km
UTM 37N_ Adindan
Figure 5.5
AIS: Depth to Groundwater Map
GTS
July 2009

5.6 Discussion

The alluvial formations of the Middle Valley in Amibara area have been predominately deposited by the Awash river and its tributaries. The fluvial deposits are composed of layers of mainly clays, silts and sands in varying proportions and sequences, with thickness of over 100m in some places (reported in Halcrow, 1985). Occasionally, they are intercalated with volcanic layers that resulted from periodic events. Boreholes sunk into these formations yield satisfactory water, which makes them water-bearing formations (aquifers). All these layers are presumably overlain by fractured volcanic rocks with varying transmissivities depending on the layer's thickness and relative geographic location to structural and volcanic features.

In general, the alluvial aquifers may be considered unconfined type with perched water tables existing locally where compacted silty layers occur at shallow depths. It has been noted in Halcrow (1985) that although confining layers may be encountered locally in the fine-textured sequences, the groundwater is believed to be in hydraulic contact regardless of geologic formation. Limited deep borehole data has however placed certain constraints on full understanding of the hydrogeology of the area and its vicinity.

The Awash flood plain in Amibara area gains recharge from rainfall, surface runoff and irrigation, while the latter is responsible for the rising groundwater levels. It is evident that with such rate of rise, the formations are not capable of fully draining the recharges (from successive irrigations) to the Awash river and adjacent plains. This is essentially due to the relatively low hydraulic conductivities of the alluvial/fluvial deposits and occurrence of relatively impermeable layers of very low conductivities. The groundwater levels in some places have now become close to surface that evaporation has become one of the important outflow components other than groundwater outflow.

High groundwater tables may give rise to secondary soil salinization due to upward leaching of salts from the shallow water table. The high evaporation rate in the Amibara area favors this condition, particularly during the fallow period. This problem could be more serious if the existing groundwater is saline. As it will be discussed in the next Chapter, the groundwater in the irrigated areas is generally saline.

CHAPTER SIX

GENERAL HYDRO-CHEMISTRY AND GROUNDWATER SALINITY

In as much as hydrologic assessments are vital to comprehensive hydrogeological investigations of surface water-groundwater interactions and effects of irrigation on the environment, hydro-chemical assessments also play their invaluable roles by providing additional evaluation techniques.

6.1 Hydro-chemical Data

Both surface water (the Awash river, canals and drains) and groundwater (piezometers and boreholes) were sampled during two field surveys for chemical analysis. Samples collected in Nov 2003 were analyzed at the Central Laboratory of Ethiopian Geological Survey while additional chemical analyses were performed at the Werer Research Center (EARO) laboratory for those collected in May 2004.

One of the practical methods of checking the quality of hydro-chemical data is computing an ionic balance for each sample (see equation below). Electro-neutrality (EN) values above 5% may indicate the analysis either contains erroneous results or does not include some ion with significant concentrations.

$$EN\ (\%) = \frac{(\Sigma \text{ cations} - \Sigma \text{ anions}) \times 100\ \%}{(\Sigma \text{ cations} + \Sigma \text{ anions})}$$

Where concentrations of cations and anions are expressed in meq / l

The chemical analysis data of 17 surface water samples and 35 groundwater samples, conducted as part of this study, are presented in Tables 6.3 a&b. Except three samples, the EN values of all the samples are within the acceptable limit of charge-balance error. Difficulty arose in determining bicarbonate ion in three samples (M_FE_Nov 03, AIP 6, AIP 10) while unusually high total iron concentrations were encountered in the later two piezometers.

While the above briefly discusses the availability of primary chemical analytical data, collection and interpretation of in-situ field tests data are dealt with in the next section (see Tables 6.1 & 6.2 for surface water and groundwater samples).

6.2 In-situ Field Tests

The hydrogen-ion activity (pH), temperature, and electrical conductivity (EC) of samples were recorded on site together with calculated TDS (mg/l) and salinity (g/l) using portable pH and EC meters. In addition to these equipments, also on-board was a turbidity meter used for samples collected from the Awash river, irrigation canals and drains.

It may be generally expected that surface water samples attain and/or reflect the surrounding temperature. Temperature measurements of samples collected from rivers, canals and drains at Amibara and Metahara ranged between 20 and 27 ^{0}C, close to day-time air temperature records during sampling periods. Relatively higher temperature readings between 27 and 35 ^{0}C were measured for samples taken from piezometers.

The Awash river has been sampled at Metahara and Amibara areas at a number of sites. Measurements of pH remain between 7.5 and 8.5 while electrical conductivity values range from 270 to 610 uS/cm. Whereas a general increase in EC values has been observed downstream, temporal considerations show that EC values decrease during high flow periods. With such electrical conductivities at irrigation intake sites, the Awash river can generally be considered suitable for irrigation on the basis of salt amount only. The detailed evaluation of the Awash river for irrigation is presented in the section 6.4 under irrigation water quality.

Irrigation canal water samples have similar pH and EC values to those of the Awash river samples collected near intakes. The AIS primary canal was sampled at seven sites from PCD 1 (near Melka Sadi intake) to PO 11, 12, 13 (at tail end) with a very slight increase in EC downstream (Table 6.1)

As it may be expected, drainage canals receiving both surface and/or sub-surface drainage water have relatively higher EC values than irrigation canals (Tables 6.1). A sample taken in August from a primary drain near AIS outfall has an EC value of about 2000 uS/cm.

Nevertheless, EC of drainage canal waters collected from deep open primary drains become less than 1 dS/m (1000 uS/cm) when joined by other drains discharging significantly excess irrigation water rejected from fields. Measured pH values for AIS drains as well as for sugarcane plantation drains including the factory effluent at Metahara are generally slightly alkaline (7.2 to 8.5).

Table 6.1 Surface Water In-situ Field Tests: Awash River, Irrigation Canals and Drains

a. Amibara (November 03)

Sr. No.	Sample ID	Description	UTM E	UTM N	EC (uS/cm)	pH	Temp (^{o}C)	Cal TDS (mg/l)	Cal Salinity (g/l)	Turbidity (FTU)	Chemical Analysis
1	AR_MS_Nov03	near Melka Sedi Intake, weir site	622961	1017802	282	8.3	23.6	172.9	0.4	205	*
2	AR_nAIP29_Nov03	Melka Sadi area, near AIP 29	620947	1024541	465	8.2	24.7	282.0	0.5	-	
3	AR_MW_Nov03	near Melka Werer river guaging st.	629071	1030168	476	8.3	24.1	290.0	0.5	216	*
4	AR_SPS_Nov03	at Sheleko pump st., near AIP 60	626690	1036590	609	8.2	23.0	367.0	0.5	217	*
5	AR_BB_Nov03	near Bolhamo bridge	631132	1045703	524	8.3	23.6	316.0	0.5	236	*
6	AR_aDO_Nov03	after AIS drain outfall, Asoba	635245	1046528	527	8.3	23.9	318.0	0.5	294	*
7	PC_PCD 1_Nov03	at PCD 1	622223	1019508	299	8.1	24.4	181.8	0.4	-	*
8	PC_PCD 2_Nov03	at PCD 2	626072	1022441	298	8.3	21.7	181.8	0.4	-	
9	PC_PCD 3_Nov03	at PCD 3	628684	1026084	292	8.2	22.1	177.7	0.4	-	
10	PC_PCD 4_Nov03	at PCD 4	630233	1030549	295	8.5	27.2	179.4	0.4	-	
11	PC_PCD 5_Nov03	at PCD 5	629994	1032444	298	8.4	23.0	180.3	0.4	228	
12	PC_PCD 6_Nov03	at PCD 6	629664	1033829	306	8.5	24.4	188.6	0.4	217	
13	PC_PO11,12&13_Nov03	at PO 11, 12 & 13; tail end	630912	1038982	314	8.5	27.0	187.9	0.4	239	
14	PD_nABA_Nov03	near ABA Head Office	630400	1029900	930	7.9	23.1	564.0	0.6	261	*
15	PD_nDO_Nov03	near AIS drain outfall	635712	1045272	341	8.4	23.3	201.0	0.4	498	*

AR=Awash River; PC=Primary Canal; PD=Primary Drain; PCD=Primary Check Drop; PO=Primary Offtake; DO=Drain Outfall

b. Metahara (November 2003)

Sr. No.	Sample ID	Description	UTM E	UTM N	EC (uS/cm)	pH	Temp (^{o}C)	Cal TDS (mg/l)	Cal Salinity (g/l)	Turbidity (FTU)	Chemical Analysis
1	AR_uAI_Nov03	just u/s Abadir intake; weir site	596139	965808	270	8.4	21.6	160.6	0.5	225	*
2	AR_AI_Nov03	at Abadir intake	596155	966031	275	8.4	21.9	165.8	0.4	222	
3	AR_AB_Nov03	near Abadir bridge	598244	973118	265	8.4	22.6	157.9	0.4	222	*
4	AR_M_Nov03	at Metahara river guaging st.	601306	978612	278	8.2	20.1	165.3	0.4	232	*
5	AR_NMF_Nov03	near nothern Metahara farm end	607790	980809	279	8.0	22.0	167.9	0.4	224	*
6	M_FE_Nov03	sugar factory effluent	600661	976434	362	7.3	25.7	218.0	0.4	238	*
7	MD_AB_Nov03	drain near Abadir bridge	598319	973230	407	8.3	21.2	244.0	0.5	239	*
8	MD_uS_Nov03	drain, farm unit S	603798	979754	317	7.9	25.6	188.8	0.4	237	*
9	MD_uT_Nov03	drain, farm unit T	606002	978994	270	8.1	20.1	164.9	0.4	215	*

AR=Awash River; AI= Abadir Intake; M= Metahara; MD=Metahara Drain; u/s=upstream

c. Amibara (May, August and September 2004)

Sr. No.	Sample ID	Description	UTM E	UTM N	EC (uS/cm)	pH	Temp (^{o}C)	Cal TDS (mg/l)	Cal Salinity (g/l)	Turbidity (FTU)	Chemical Analysis
1	AR_MS_May04	near Melka Sadi intake, weir site	622840	1017600	420	8.4	24.6	254	0.5	185	*
2	AR_MW_May04	near Melka Werer river guaging st.	628984	1029970	902	8.2	26.2	546	0.6	197	
3	AR_MS_Aug04	near Melka Sedi intake, weir site	622840	1017600	344	7.8	-	206	0.4	1000	
4	AR_MW_Aug04	near Melka Werer river guaging st.	628984	1029970	312	7.6	-	188	0.4	>>1000	
5	AR_SPS_Aug04	at Sheleko pump st., near AIP 60	626570	1036416	324	7.9	-	195	0.4	>>1000	
6	AR_BB_Aug04	near Bolhamo bridge	631050	1045473	308	7.7	-	184.9	0.4	>>1000	
7	AR_nDO_Aug04	near AIS drain outfall	635163	1046316	380	8.3	-	176.3	0.4	>>1000	
8	AR_aDO_Sep04	after AIS drain outfall, Asoba area	635163	1046316	294	8.3	-	176.3	0.4	>>1000	
9	PD_nDO_Aug04	near AIS drain outfall	635630	1045091	2050	8.1	-	1228	1.0	427	

AR=Awash River; PC=Primary Canal; PD=Primary Drain; PCD=Primary Check Drop; PO=Primary Offtake; DO=Drain Outfall

It has been mentioned earlier that one of the problems in AIS is siltation of canals. During the dry period, the turbidity of the Awash river, canals and drains is below 300 FTU with slight increase reaching about 450 FTU for the AIS primary drain near outfall (Tables 6.1). Not surprisingly, tremendous increase in turbidity of the Awash river during the rainy season occurs, FTU much, much higher than 1000. Sediment inputs from tributaries contribute to the high sediment load of the Awash that also find a way to irrigation canals. With no scour sluice

built, the new intake at Melka Sadi allows sediment to enter canals, requiring dredging annually.

On the other hand, the majority of the piezometers samples have pH values between 7.0 and 8.0. Strongly alkaline groundwater samples with pH greater than 10 are recorded from AIP 3/1, AIP 3/2, AIP 10/1, AIP 27/1 and AIP 27/2 samples, which are located in the former Melka Sadi Banana farm. On the other hand, AIP 6 and AIP 10 are acidic with pH values close to 6.0.

The electrical conductivities of the piezometers/observation wells vary from about 1,000 uS/cm to 30,000 uS/cm. As it can be seen in Tables 6.2 a&b, above 75% of the piezometers have measured EC values greater than 2 mS/cm, representing largely the unconfined alluvial aquifer covering the irrigated farms. The detailed investigation of the spatial variation of groundwater salinity in AIS is separately addressed in section 6.5.

Although the groundwater in Amibara is generally saline, there are several wells in Amibara area that are primarily pumped for the purpose of providing drinking water for the community. The ABA and Werer town boreholes serve quite a lot of inhabitants while their EC values are 1.77 & 2.74 mS/cm respectively, which are a bit above the European Community recommended limit of 1000 uS/cm for potable water supply.

6.3 Major Ions and Water Types

The major cations present in natural waters include sodium, potassium, magnesium and calcium while bicarbonate, carbonate, chloride and sulphate are the dominant anions.

Compilation and presentation of chemical data in a convenient manner for visual inspection using graphical methods is an important task in groundwater investigations (Freeze and Cherry, 1979). Trilinear plots allow comparisons between a large number of samples whereby clustering of samples could carefully be observed. Figures 6.1 a & b are Piper plots for samples collected from surface waters (the Awash, irrigation canals and drains) and groundwater (piezometers and boreholes). In addition to these, the samples chemical compositions (water types of sampling sites) with their locations are spatially portrayed in Figure 6.2.

Table 6.2a Groundwater In-situ Field Test Data: Piezometers and Boreholes

a. Nov 2003

Sr. No.	Sample ID	UTM E	UTM N	Depth to Water Level (m)	EC (mS/cm)	pH	T (°C)	Cal TDS (mg/l)	Cal Salinity (g/l)	Chemical Analysis
1	AIP 3	624013	1023461	2.16 (muddy)						
2	AIP 3/1	624017	1023468	3.33	13.33	10.4	29.6	8140	6.1	*
3	AIP 3/2	624021	1023472	3.90	1.69	10.2	30.2	1021	0.9	
4	AIP 6	625416	1022335	2.32	7.37	6.1	33.6	4380	3.2	*
5	AIP 7	622533	1025399	3.56	20.40	7.2	28.2	12150	10.1	*
6	AIP 9	622158	1026950	8.08	4.53	7.6	32.4	2710	2.0	
7	AIP 10	625723	1024871	2.88	10.74	5.8	33.1	6470	4.7	*
8	AIP10/1	625720	1024866	4.61	4.06	10.2	33.8	2430	1.8	
9	AIP10/2	625714	1024862	3.08	2.75	7.3	33.7	1639	1.3	
10	AIP10/3	625708	1024855	2.12 (muddy)						
11	AIP 11	623114	1028338	4.12	10.07	7.6	29.8	6020	4.4	
12	AIP 12	624241	1026951	3.80	5.50	7.2	27.5	3280	2.4	
13	AIP 14	627274	1024361	2.70	11.56	6.9	30.0	6880	5.1	*
14	AIP14/3	627283	1024347	2.04 (muddy)						
15	AIP 18	628133	1025888	4.02	11.53	7.7	30.1	6910	5.1	
16	AIP 19	626894	1027990	3.80	9.50	7.9	29.2	5670	4.1	
17	AIP 21	630322	1028876	3.15	5.60	8.2	29.2	3390	2.4	
18	AIP 22	629117	1029240	1.70						
19	AIP 23	626354	1025754	3.10	3.99	7.7	30.9	2400	1.8	
20	AIP 25	624065	1026291	4.63 (muddy)						
21	AIP 27	623460	1021443	3.60	2.33	7.6	30.5	1372	1.1	
22	AIP 27/1	623466	1021450	3.22	1.76	10.6	30.8	1054	0.9	
23	AIP 27/2	623462	1021447	3.45	2.27	10.3	30.2	1359	1.1	
24	AIP 27/3	623455	1021447	2.94 (muddy)						
25	AIP 28	621809	1022997	2.08	1.43	7.5	29.4	869	0.8	
26	AIP 30	620880	1027180	1.54 (muddy)						
27	AIP 32	628602	1032893	5.05	1.78	7.6	29.0	1067	0.9	*
28	AIP 35	630922	1032954	2.72	8.98	7.8	29.5	5430	3.9	
29	AIP 37	632057	1033895	3.16	3.16	9.3	28.7	1899	1.4	
30	AIP 39	627746	1038000	7.1 (muddy)						
31	AIP 40	630040	1038005	3.32	1.75	7.8	29.3	1064	0.9	
32	AIP 41	630711	1036251	1.60	9.00	7.8	28.4	5360	3.9	
33	AIP 42	632693	1036644	2.29	29.80	7.8	28.5	17920	16.8	*
34	AIP 43	632109	1038139	2.38	10.88	7.5	29.3	6510	4.8	
35	AIP 44	630698	1039192	2.43	13.54	9.6	29.1	8140	6.2	
36	AIP 46	632092	1039914	3.95	21.00	7.7	30.7	12590	10.4	
37	AIP 47	634240	1038898	2.40	9.87	7.8	27.5	5950	4.3	
38	AIP 50	632996	1041779	3.12	15.12	9.5	28.8	8990	7.0	
39	AIP 52	635975	1040028	5.72	10.78	8.9	27.8	6420	4.7	
40	AIP 54	636998	1041713	6.69	5.49	8.6	27.7	3320	2.4	
41	AIP 55	633899	1045397	3.18	2.79	7.3	29.9	1688	1.3	
42	AIP 60	627084	1036343	6.96	0.93	7.5	33.6	550	0.6	
43	AIP 62	631444	1045102	6.72	21.00	7.3	31.0	12640	10.6	
44	AIP 63	629462	1035127	4.18	7.49	7.4	30.0	4520	3.2	
45	AIP 64	631692	1035507	2.13 (bent pipe, difficult for sampling)						
46	AIP 65	630504	1037889	1.70	1.14	7.6	29.3	695	0.7	
47	PP 1	628833	1029710	4.80	1.71	7.7	29.0	1030	0.9	
48	P 2	627924	1034244	6.58	2.46	7.2	30.3	1458	1.2	
49	P 11	624973	1024211	2.00	5.65	7.9	30.9	3410	2.4	

Table 6.2b Groundwater In-situ Field Test Data: Piezometers and Boreholes

b. May 2004

Sr. No.	Sample ID	UTM E	UTM N	Depth to Water Level (m)	EC (mS/cm)	pH	T (^{o}C)	Cal TDS (mg/l)	Cal Salinity (g/l)	Chemical Analysis
1	AIP 3/1	624017	1023468	3.47	12.67	10.6		7690	5.7	
2	AIP 3/2	624021	1023472	4.37	1.73	10.7	31.0	1036	0.9	
3	AIP 6	625416	1022335	2.40	7.62	6.0	30.7	4530	3.3	
4	AIP 7	622533	1025399	3.90	19.57	7.0	27.9	11800	9.7	
5	AIP 10	625723	1024871	3.20	8.84	6.0	33.3	5400	3.8	
6	AIP 10/1	625720	1024866	5.15	4.03	10.5	33.6	2390	1.8	
7	AIP 10/2	625714	1024862	3.05	2.71	6.7	33.1	1619	1.3	
8	AIP 10/3	625708	1024855	1.80	13.84	7.9	31.9	8360	6.4	
9	AIP 12	624241	1026951	4.80	5.34	7.0	28.6	3120	2.3	*
10	AIP 14	627274	1024361	1.18	7.14	7.7	29.3	4290	3.1	
11	AIP 14/3	627283	1024347	1.14	1.56	7.5	29.0	935	0.9	
12	AIP 18	628133	1025888	4.00	11.38	7.5	31.1	6990	5.0	*
13	AIP 19	626894	1027990	4.70	9.55	7.9	31.6	5810	4.3	*
14	AIP 21	630322	1028876	4.20	5.42	8.4	30.4	3280	2.4	*
15	AIP 23	626354	1025754	1.56	4.66	7.8	30.4	2830	2.0	*
16	AIP 27	623460	1021443	2.47	2.71	7.8	34.0	1613	1.3	*
17	AIP 27/1	623466	1021450	2.76	1.87	10.6	34.4	1103	1.0	
18	AIP 27/2	623462	1021447	3.38	2.15	10.5	33.7	1324	1.1	
19	AIP 28	621809	1022997	1.20	1.81	7.4	29.3	1077	0.9	*
20	AIP 32	628602	1032893	5.18	1.67	7.7	30.8	1036	0.9	
21	AIP 35	630922	1032954	2.53	9.14	7.7	31.4	5530	4.0	*
22	AIP 37	632057	1033895	3.39	3.18	9.5	31.9	1934	1.5	*
23	AIP 40A	630040	1038005	3.24	1.40	7.7	28.5	840	0.8	*
24	AIP 41	630711	1036251	1.65	8.51	7.3	31.7	5140	3.7	*
25	AIP 42	632693	1036644	2.51	29.10	7.8	29.1	17580	16.2	
26	AIP 43	632109	1038139	1.91	5.14	7.5	30.3	3060	2.2	*
27	AIP 44	630698	1039192	3.37	12.65	9.7	32.1	7680	5.8	*
28	AIP 46	632092	1039914	4.78	19.27	7.3	32.0	12220	9.9	*
29	AIP 47	634240	1038898	3.06	9.65	7.8	29.9	5800	4.2	*
30	AIP 50	632996	1041779	3.80	14.52	9.6	30.7	8800	6.8	*
31	AIP 52	635975	1040028	5.90	11.53	8.8	29.7	6.92	5.1	*
32	AIP 54	636998	1041713	6.81	5.08	8.5	31.2	3070	2.2	*
33	AIP 55	633899	1045397	2.72	2.50	7.3	34.0	1563	1.2	*
34	AIP 60	627084	1036343	7.50	2.59	8.9	41.4	1593	1.2	*
35	AIP 62	631444	1045102	6.73	19.35	7.2	32.8	11630	9.5	*
36	AIP 63	629462	1035127	4.68	6.85	7.5	29.2	4110	2.9	*
37	AIP 65	630504	1037889	2.36	0.96	7.4	29.0	574	0.6	*
38	P1	628833	1029710	5.37	1.56	7.7	29.1	936	0.9	*
39	P2	627924	1034244	9.69	2.29	7.2	36.1	1377	1.1	*
40	P9	632300	1044901	6.40	3.15	7.6	32.9	1898	1.4	*
41	P11	624973	1024211	1.37	6.00	8.0	33.0	3630	2.6	
42	ABA BH	629058	1030475		1.77	8.1		1063	0.9	*
43	Werer BH	629488	1031643		2.74	8.9		1657	1.3	*

The following points were deduced from the plots, maps/figures and tables:

- The Awash river water is of Na-Ca-HCO_3. As mentioned earlier, the EC of the Awash river varies seasonally, which may also affect the water type. Change to a Na-HCO_3 - Cl ty pe has been noticed for the Awash river at Melka Sadi intake sampled on May, which is during low flow period enriched with relatively more soluble salts.
- Piezometer samples with relatively higher EC values (greater than 10 mS/cm) are of Na-Cl-SO4 and Na-Cl types.
- The relative dominance of sodium over calcium decreases in piezometers located close to either the Awash river or the primary canal. Piezometers located on the right canal bank downstream of PCD 4 are Na-Ca-Cl type.
- In general bicarbonate is considerable in most piezometer samples with electrical conductivities less than 10,000 uS/cm that plotted in the central part of the diamond-shaped field in the piper plot, which could be grouped as HCO3, Cl + SO4 types. Common water types in this water are also shown grouped in Figure 6.1.
- Relative dominance of bicarbonate is observed in piezometers and boreholes with EC values less than 3 000 uS/cm, located along the Awash river.

While temporal variations may be important for surface water investigations, the groundwater however varies spatially, noticeably influenced by river-aquifer and canal-aquifer transfer.

Table 6.3 Chemical Analysis Data of Surface and Groundwater Data

a. Awash river, irrigation canals & drains

Sample ID	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Fe (mg/l)	HCO_3^- (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^{2-} (mg/l)	F^- (mg/l)	CO_3^{2-} (mg/l)	SiO_2 (mg/l)	CO_2 (mg/l)	HBO_2 (mg/l)
a. Amibara														
AR_MS_Nov03	32.5	5.9	23	4.5	0.7	144	11	4	3.99	1.26	-	30	4	0.55
AR_MS_May04	77.5	14.5	20	3.2	nd	200	43	37	nd	nd	-	nd	nd	nd
AR_MW_Nov03	71	7.1	22	6	0.6	215	28	15	3.1	1.78	-	30	6	0.69
AR_SPS_Nov03	92	7.8	25	6	0.2	264	39	21	2.22	2.12	-	33	4	1.70
AR_BB_Nov03	80	7.6	21	5	0.4	238	32	16	<0.04	1.96	-	34	5	0.96
AR_aDO_Nov03	81	7.2	19	5	0.2	238	31	14	<0.04	1.98	-	35	4	1.65
PC_PCD1_Nov03	32	6.5	23	4.5	0.2	149	12	5	2.66	1.28	-	29	4	0.69
PD_nABA_Nov03	104	8.1	60	16	< 0.1	283	128	29	13.29	1.24	-	24	33	2.30
PD_nDO_Nov03	36	6.7	25	6	0.8	163	13	6	1.33	1.3	-	28	23	1.38
b. Metahara														
AR_uAI_Nov03	27	5.2	20.5	4	0.7	137	9	7	3.1	1.25	-	26	4	1.31
AR_AB_Nov03	26	5.1	20.5	4	0.5	129	9	8	3.1	1.06	-	26	3	1.31
AR_M_Nov03	26.5	5.4	22	4	0.6	137	9	7	1.33	1.19	-	28	5	0.89
M_FE_Nov03	36	13.1	39	6	3	?	22	<1	0.89	0.98	-	37	245	0.82
AR_NMF_Nov03	27	5.6	20	5	0.7	149	9	8	0.89	1.16	-	28	5	0.82
MD_AB_Nov03	45	6.7	27	7	0.4	165	25	23	1.77	1.2	-	27	7	2.06
MD_uS_Nov03	28	6.6	26	5	0.3	160	10	14	<0.04	1.19	-	27	15	0.89
MD_ uT_Nov03	27	5.4	21	3	0.6	142	10	8	1.77	1.16	-	27	4	3.44

Note: see Tables 6.1 a,b,c for sample location, descriptions and in-situ field tests

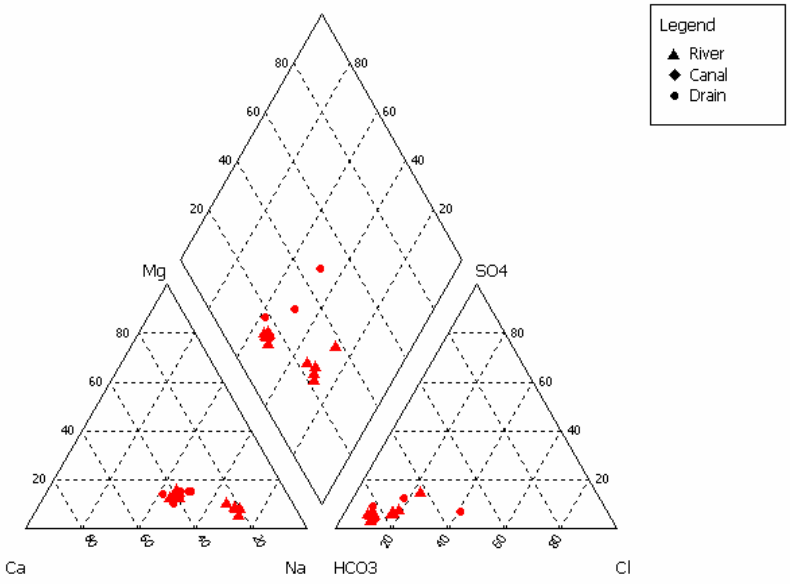
b. Piezometers and boreholes

Sample ID	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Fe (mg/l)	HCO_3^- (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^{2-} (mg/l)	F^- (mg/l)	CO_3^{2-} (mg/l)	SiO_2 (mg/l)	CO_2 (mg/l)	HBO_2 (mg/l)
AIP 3/1	3075	31	12	3	0.2	52	3238	1146	5.32	4.53	542	2	-	5.4
AIP 6	340	11.6	260	40	130	?	2670	540	3.54	6.69	-	6	-	4.8
AIP 7	4550	28	42	35	1.7	34	5089	3279	3.1	0.67	-	1	38	18.1
AIP 10	325	4.6	75	50	1875	?	4060	1650	19.1	0.63	-	30	-	6.7
AIP 12	483	28.2	381	34.3	nd	707	1008	305	nd	nd	-	nd	nd	nd
AIP 14	2250	64	15	20	0.2	227	3088	1102	3.54	5.91	-	24	276	28.6
AIP 18	2507	31.3	34.9	7.3	nd	1205	2741	292	nd	nd	63.0	nd	nd	nd
AIP 19	2287	16.0	7.6	8.7	nd	1245	2603	207	nd	nd	-	nd	nd	nd
AIP 21	1143	25.8	8.4	1.7	nd	1427	883	195	nd	nd	67.5	nd	nd	nd
AIP 23	1020	16.8	66.1	3.9	nd	1074	398	702	nd	nd	67.5	nd	nd	nd
AIP 27	387	11.0	90.1	32.6	nd	1060	187	200	nd	nd	-	nd	nd	nd
AIP 28	213	15.3	112	9.3	nd	637	183	75.4	nd	nd	-	nd	nd	nd
AIP 32	305	8.6	40	25	<0.1	695	111	183	3.99	1.18	-	32	24	4.7
AIP 35	1052	37.5	565	120	nd	478	2225	707	nd	nd	-	nd	nd	nd
AIP 37	464	19.5	143	44.6	nd	879	612	108	nd	nd	-	nd	nd	nd
AIP 40A	166	16.0	113	8.5	nd	562	80.5	167	nd	nd	-	nd	nd	nd
AIP 41	1189	12.5	331	97.7	nd	516	1979	611	nd	nd	-	nd	nd	nd
AIP 42	7400	7.2	60	100	0.6	1114	7186	5961	194.9	2	-	21	30	19.5
AIP 43	457	22.7	332	89.7	nd	683	950	391	nd	nd	-	nd	nd	nd
AIP 44	1135	62.5	877	206	nd	312	3237	529	nd	nd	-	nd	nd	nd
AIP 46	3607	41.1	181	34	nd	698	4919	1501	nd	nd	-	nd	nd	nd
AIP 47	2330	17.2	58.1	5.6	nd	1620	1853	842	nd	nd	63.3	nd	nd	nd
AIP 50	2946	45.7	92.2	65.4	nd	528	3129	1472	nd	nd	21.9	nd	nd	nd
AIP 52	2250	21.5	16.4	5.1	nd	840	2314	1231	nd	nd	37.2	nd	nd	nd
AIP 54	1108	10.2	21.3	4.9	nd	1288	654	405	nd	nd	76.8	nd	nd	nd
AIP 55	227	31.7	161	61	nd	746	221	340	nd	nd	-	nd	nd	nd
AIP 60	380	6.7	61.2	57.1	nd	774	375	167	nd	nd	-	nd	nd	nd
AIP 62	3342	58.3	1264	10.9	nd	1084	5255	1616	nd	nd	62.1	nd	nd	nd
AIP 63	1231	21.5	216	12.2	nd	976	1075	801	nd	nd	-	nd	nd	nd
AIP 65	91.5	12.9	95.4	24.8	nd	495	66.3	92.2	nd	nd	-	nd	nd	nd
P1	206	11	96.7	27.3	nd	670	146	142	nd	nd	-	nd	nd	nd
P2	348	11.7	119	15.6	nd	917	270	113	nd	nd	-	nd	nd	nd
P9	442	12.9	94.2	70.7	nd	1005	288	387	nd	nd	-	nd	nd	nd
ABA_BH	213	90	161	24	nd	834	187	126	nd	nd	-	nd	nd	nd
Werer_BH	394	9.7	109	54.3	nd	922	345	239	nd	nd	-	nd	nd	nd

Notes: see Tables 6.2 a,b for sample location, descriptions and in-situ field tests
nd: not determined

Figure 6.1a & b Piper Plots: Surface Water and Groundwater Samples

a. Surface water



b. Groundwater

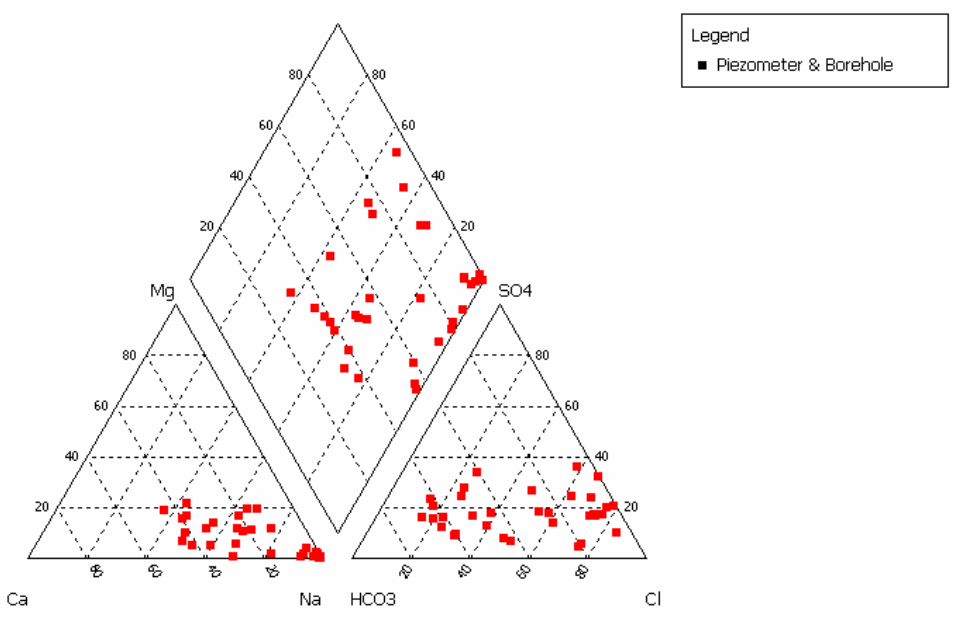


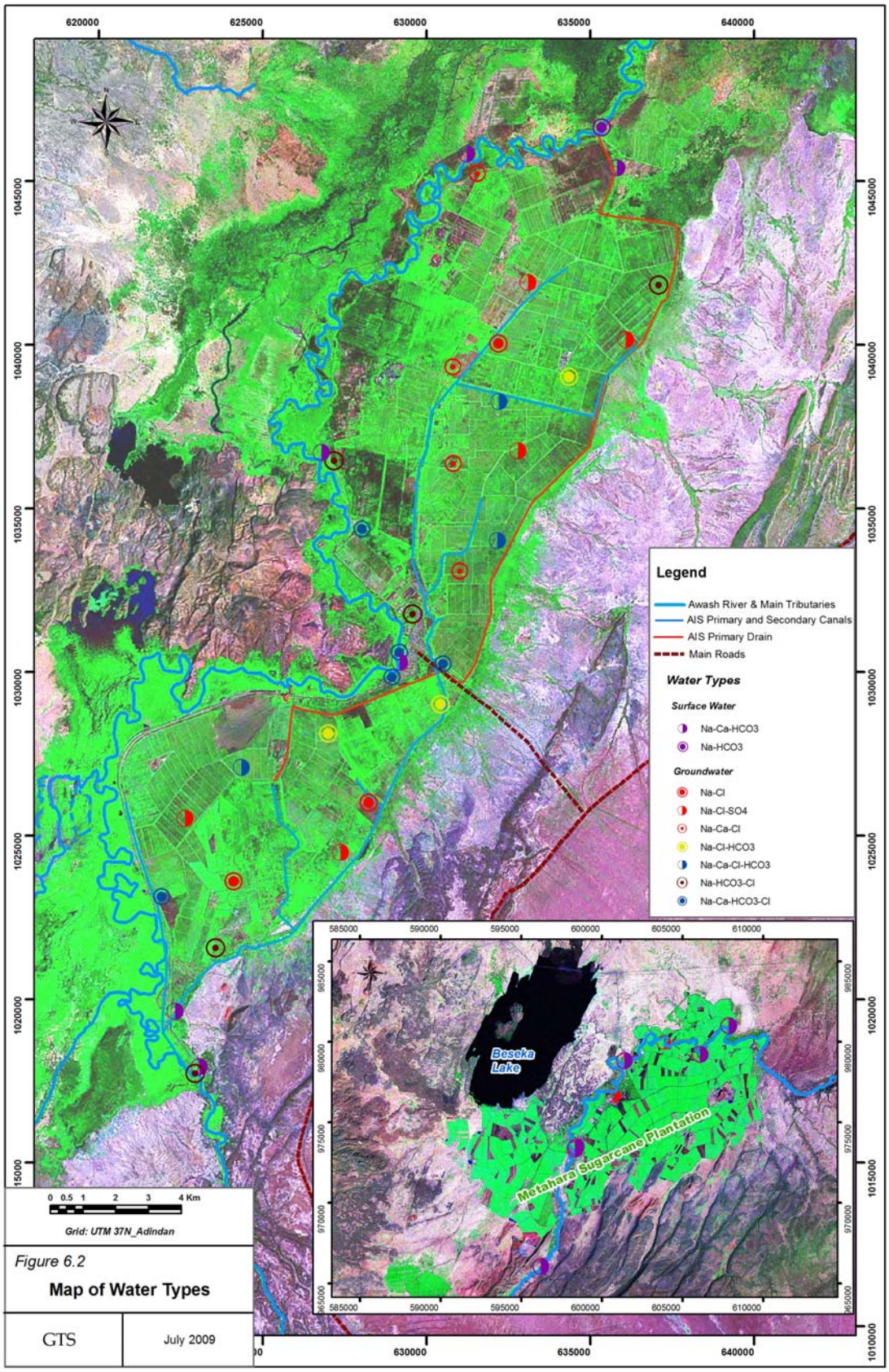
Table 6.4 Relationships b/n Water Types, Salinity, Distance to Water Courses and Season

a. Groundwater

Sample ID	Water Type
Extremely Saline (EC > 10 mS/cm)	
AIP 3/1	Na-Cl
AIP 18	Na-Cl
AIP 46	Na-Cl
AIP 7	Na-Cl-SO4
AIP 14	Na-Cl-SO4
AIP 42	Na-Cl-SO4
AIP 50	Na-Cl-SO4
AIP 52	Na-Cl-SO4
Extremely to Highly Saline (EC > 7.5 mS/cm), close to primary canal or river	
AIP 44	Na-Ca-Cl
AIP 62	Na-Ca-Cl
AIP 35	Na-Ca-Cl
AIP 41	Na-Ca-Cl
Highly Saline (EC 5 - 10 mS/cm)	
AIP 19	Na-Cl-HCO3
AIP 21	Na-Cl-HCO3
AIP 47	Na-Cl-HCO3
Moderately saline (EC 2.5 - 5 mS/cm), close to secondary canals	
AIP 12	Na-Ca-Cl-HCO3
AIP 37	Na-Ca-Cl-HCO3
AIP 43	Na-Ca-Cl-HCO3
Moderately Saline (EC 2.5 - 5 mS/cm)	
AIP 54	Na-HCO3-Cl
AIP 27	Na-HCO3-Cl
Werer BH	Na-HCO3-Cl
AIP 60	Na-HCO3-Cl
Slightly Saline (EC 0.75 - 2.5 mS/cm), close to Awash river or canal	
AIP 28	Na-Ca-HCO3-Cl
P1	Na-Ca-HCO3-Cl
P2	Na-Ca-HCO3-Cl
ABA BH	Na-Ca-HCO3-Cl
AIP 40A	Na-Ca-HCO3-SO4
AIP 65	Ca-Na-HCO3
Others	
AIP 63	Na-Cl-SO4-HCO3
AIP 23	Na-HCO3-SO4-Cl
P9	Na-HCO3-Cl-SO4
AIP 32	Na-HCO3-SO4
AIP 55	Na-Ca-Mg-HCO3-SO4-Cl

b. Surface water

Sample ID	Water Type
Awash River: Amibara area	
AR_MS_Nov03	Na-Ca-HCO3
AR_MS_May04	Na-HCO3-Cl
AR_MW_Nov03	Na-Ca-HCO3
AR_SPS_Nov03	Na-Ca-HCO3
AR_BB_Nov03	Na-Ca-HCO3
AR_aDO_Nov03	Na-HCO3
Awash River: Metahara area	
AR_uAI_Nov03	Na-Ca-HCO3
AR_AB_Nov03	Na-Ca-HCO3
AR_M_Nov03	Na-Ca-HCO3
AR_NMF_Nov03	Na-Ca-HCO3
AIS: Canal & Drain	
PC_PCD1_Nov03	Na-Ca-HCO3
PD_nDO_Nov03	Na-Ca-HCO3
PD_nABA_Nov03	Na-Ca-HCO3-Cl
MSF: Drain	
MD_AB_Nov03	Na-Ca-HCO3
MD_uS_Nov03	Ca-Na-HCO3
MD_ uT_Nov03	Na-Ca-HCO3


620000
625000
630000
635000
640000
1045000
1040000
1035000
1030000
1025000
1020000
1015000
1010000
Legend
Awash River & Main Tributaries
AIS Primary and Secondary Canals
AIS Primary Drain
Main Roads
Water Types
Surface Water
Na-Ca-HCO3
Na-HCO3
Groundwater
Na-Cl
Na-Cl-SO4
Na-Ca-Cl
Na-Cl-HCO3
Na-Ca-Cl-HCO3
Na-HCO3-Cl
Na-Ca-HCO3-Cl
585000
590000
595000
600000
605000
610000
985000
980000
975000
970000
965000
Beseka Lake
Metahara Sugarcane Plantation
0 0.5 1 2 3 4 Km
Grid: UTM 37N_Adindan
Figure 6.2
Map of Water Types
GTS
July 2009

6.4 Irrigation Water Quality

The importance of irrigated agriculture in the Awash Valley has already been mentioned in this study. In line with this is the need to appraise the quality of available irrigation water supply. The temporal and spatial variations of the Awash river water quality at critical sampling points have been evaluated taking into consideration potential sources of salts.

The Awash water quality evaluation for irrigation requires assessing suitability of the Awash water at selected monitoring sites in the valley in view of short and long-term effects on crops, soil and water resources. It also needs to come up with invaluable information on key management issues related to irrigated- agriculture in particular and the environment in general.

The amount and kind of salt present in water essentially determine the quality of water for irrigation. One of the mostly widely used irrigation water quality classification system is the USDA system (Table 6.5) The salinity and sodicity of irrigation water are indicated by electrical conductivity (EC) and sodium-adsorption ratio (SAR) respectively with respect to their effects on crops and soils with potential management requirements.

The SAR is calculated using the following equation (Richards, 1954):

$$SAR = \frac{(Na^{+})\ldots\ldots\ldots}{[(Ca^{2+} + Mg^{2+}) / 2]^{0.5}}$$

Where concentrations of the cations are expressed in meq/l

Table 6.5 Classification of Irrigation Water (Salinity & Sodicity)

a. Irrigation Water Salinity

Salinity Class		EC (uS/cm)	Equivalent Salt Concentration (g/l)
C1	Low salinity water	< 250	< 0.2
C2	Medium salinity water	250 - 750	0.2 - 0.5
C3	High salinity water	750 - 2250	0.5 - 1.5
C4	Very high salinity water	> 2250	1.5 - 3.0

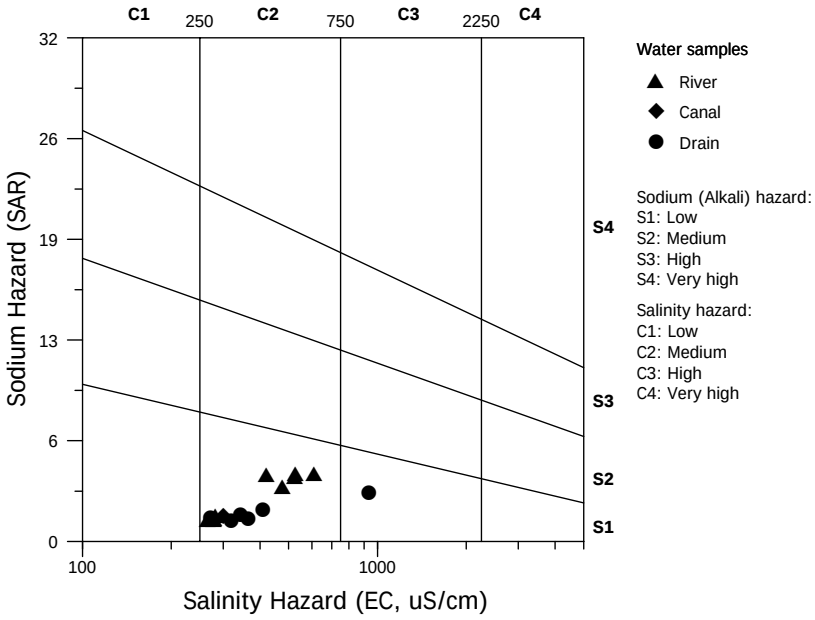
b. Irrigation Water Sodicity

Sodium Class		SAR
S1	Low sodium water	< 10
S2	Medium sodium water	10 -18
S3	High sodium water	18 - 26
S4	Very high sodium water	> 26

Source: Richards (1954) and Booker Tropical Soil Manual (Booker Tate, 1991)

It has been mentioned earlier that the Awash river was sampled at several stations in the reach between Metahara and Amibara which are typical water sites being used for irrigation. Wilcox diagram in Figure 6.3 shows the Awash river, irrigation canal and drainage samples collected from Metahara and Amibara area plotted within C2-S1 field, indicating medium salinity and low sodium (alkali) hazard. This type of water can be used if moderate amount of leaching occurs while moderately salt-tolerant crops can be grown in most cases without special practices for salinity control.

Figure 6.3 Wilcox Diagram: Awash River, Irrigation Canal and Drain Samples



As for drainage waters, it has been described in the preceding section that EC values vary partly depending on the amount of rejected direct irrigation flows. In the Figure 6.3, only one drainage sample collected from AIS primary drain near drain outfall is shown falling within C3-S1 (high salinity and low sodium hazard) field. Continuous use of waters with electrical conductivities of 750 uS/cm and above could have a salinizing effect on the soil. If long-term usage of drainage waters is considered as an option in certain pockets of AIS, blending of the relatively saline drainage water with the good quality canal water as well as salt-tolerant plants may be required to be used for cultivation.

Boron is an important minor constituent usually determined for irrigation water quality evaluations. Concentrations of HBO_2 in the Awash water samples range from 0.5 mg/l to 1.7 mg/l, with an increase in amounts in drain water and groundwater samples (see Tables 6.3a&b). Although small amounts of boron are essential to plant growth, relatively higher concentrations can be harmful especially for citrus fruit trees. Therefore, the importance of boron determination would be for the upper valley schemes where orange trees are grown in

large irrigated areas. It has been noted in Hem (1992) that some thermal waters may contain significant amounts of boron, hence important to sample thermal springs for chemical analysis in the Awash Valley if possible sources of boron in the Awash river are to be studied.

Last but not least considered here under irrigation water quality is the residual sodium carbonate (RSC). Applying waters containing carbonate plus bicarbonate concentration greater than calcium plus magnesium, may potentially increase sodium hazard since the bivalent cations may precipitate as carbonates leaving the soil solution to be relatively concentrated in sodium (Richards, 1954 and reference cited therein). The RSC is given as:

RSC (Residual Na_2CO_3) = $(CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$

Where ionic constituents are expressed in meq/l

Calculated RSC values for the Awash river samples range between 1.25 and 2.5 meq/l. According to Richards (1954), waters with such RSC value are considered as marginally suitable. With good management practices and proper use of amendments, marginal waters might be successfully used for irrigation.

On the other hand, the irrigation quality of the Awash river upstream and downstream of the study area were examined using data compiled in the Awash Master Plan Study (Halcrow, 1989) as collected from several studies cited therein (Sogreah 1965; Halcrow 1978; MacDonald 1985; Gibb, 1975 and others). The Awash at Wonji can be classified as C1-S1 and C2-S1 types since EC values are on the borderline of low to moderate salinity hazard. Sampling sites downstream of Amibara area in the Middle Valley and further downstream in the Lower Valley from which quality data has been evaluated, include Awash at Kuda, Mile, Tendaho, Dubti, DitBahri and Asaita. Reported average EC values for these stations range between 300 and 500 uS/cm, implying that the Awash river would generally be classified as having a moderate salinity hazard.

From all the available data, the salinity of the Awash river has been observed to generally increase downstream. Quite a number of thermal springs are hydraulically connected to the Awash river that may partially contribute to the salt load downstream. For example, well-known thermal springs with EC values above 2 mS/cm include Sodere and Filwuha, that supply certain amount of solutes to the Awash d/s of Wonji and u/s of Melka Werer respectively. In addition to the thermal springs, return flows from the various farms are also considered as potential salt contributors. Return flows are either directly discharged into the Awash or are diverted to nearby water courses that ultimately re-join the main river. As

drainage waters usually contain more soluble salts than irrigation waters, the effect on downstream reaches might be significant if not diluted with relatively fresh surface waters coming from the tributaries of the Awash.

On the other hand, the salinity of the Awash river varies seasonally. Measured EC at Melka Werer in May 04 (see Table 6.1) is about 900 uS/cm, indicating that the Awash could contain significant amounts of salts during low flow period while at the same time the relative natural dilution of the received saline thermal springs and return flows could also have been proportionally decreased. With increase in abstraction upstream for irrigation, the Awash river would even be more concentrated in salts for downstream schemes.

In general, EC of the Awash river during low flow period is expected to exceed 750 uS/cm at some monitoring sites within the middle and lower Awash valleys. Diverted irrigation water from the Awash at this time of the year is likely to impose a high salinity hazard (C3) and that it is not recommended to be applied on soils with restricted drainage. It's furthermore suggested in Richards (1954) that even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

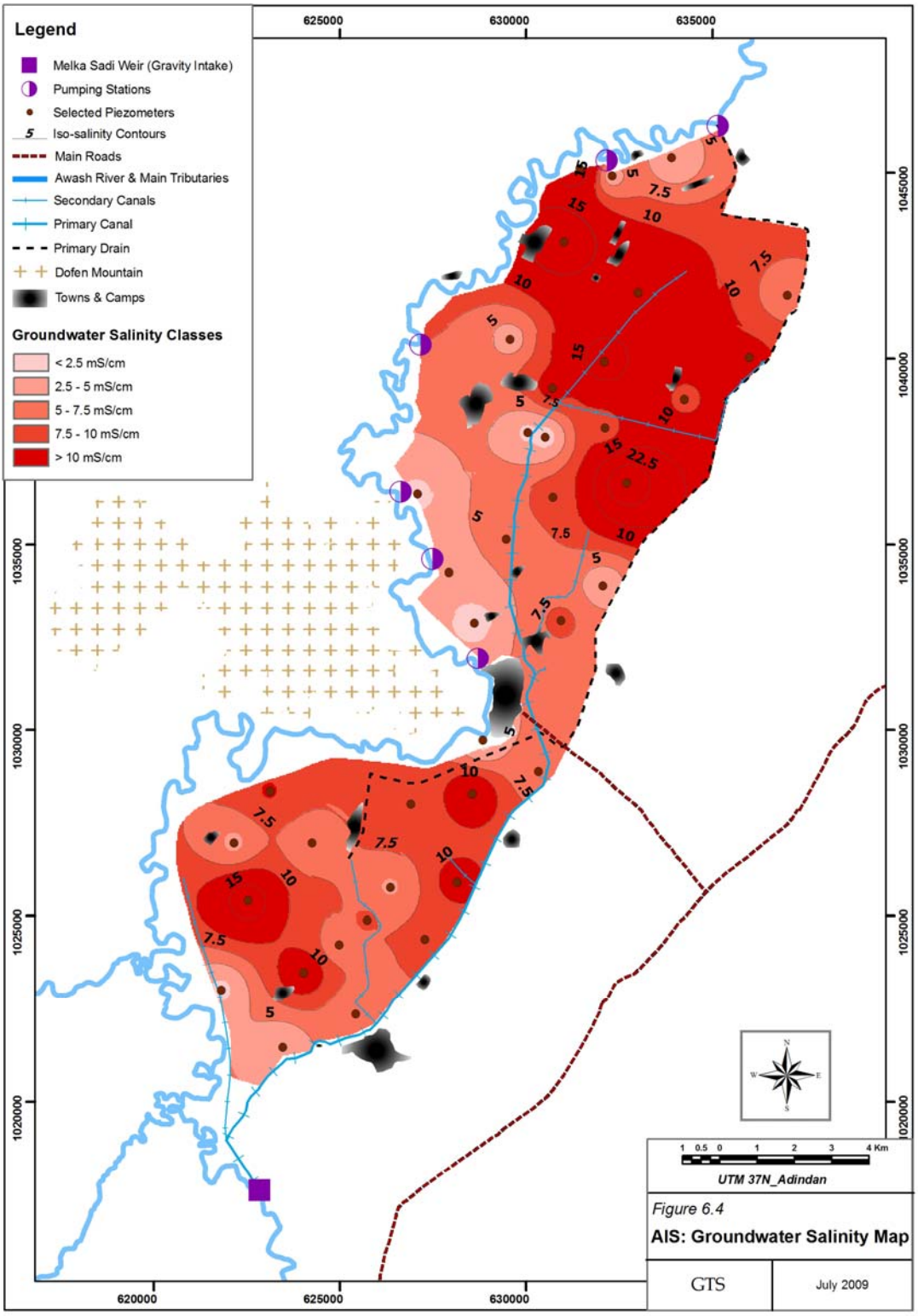
6.5 Spatial Variation of Groundwater Salinity

It has been mentioned earlier that water levels and electrical conductivity of the piezometers/observation wells are measured monthly by the Awash Basin Authority. Similar to the groundwater flow analysis, monthly average EC values of piezometers for the period between July 03 and June 04 were calculated. The readings taken in Nov 2003 and May 2004 as part of this study were also cautiously included. A total of 37 selected piezometers have been used to prepare the raster surface in Figure 6.4. Appropriate salinity classes have been chosen to spatially exhibit the distribution of groundwater salinity in Amibara.

Table 6.6 Distribution of Groundwater Salinity in AIS

No.	Groundwater Salinity Class	Description	EC (mS/cm)	*Area (ha)	% Area
1	GWS 1	Slightly Saline	< 2.5	318.4	2.1
2	GWS 2	Slightly to Moderately Saline	2.5 - 5	1579.0	10.4
3	GWS 3	Moderately Saline	5 - 7.5	4870.7	32.0
4	GWS 4	Moderately to Highly Saline	7.5 - 10	3902.2	25.6
5	GWS 5	Highly Saline	> 10	4561.4	29.9
			Total	**15231.7**	**100.0**

* refers to gross area under investigation


Legend
Melka Sadi Weir (Gravity Intake)
Pumping Stations
Selected Piezometers
Iso-salinity Contours
Main Roads
Awash River & Main Tributaries
Secondary Canals
Primary Canal
Primary Drain
Dofen Mountain
Towns & Camps
Groundwater Salinity Classes
< 2.5 mS/cm
2.5 - 5 mS/cm
5 - 7.5 mS/cm
7.5 - 10 mS/cm
> 10 mS/cm
625000
630000
635000
1045000
1040000
1035000
1030000
1025000
1020000
620000
1 0.5 0 1 2 3 4 Km
UTM 37N_Adindan
Figure 6.4
AIS: Groundwater Salinity Map
GTS
July 2009

It can be seen from Table 6.6 that more than 85 % of AIS has been mapped as having groundwater salinity above 5 mS/cm, indicating the groundwater in Amibara is generally saline. About 30 % is highly saline with EC above 10 mS/cm, considerable in areas of Melka Werer and Ambash farms.

Considerable part of the Melka Sadi plain is moderately to highly saline with EC between 7.5 and 10 mS/cm. The secondary canal running nearly S-N in the middle of the plain may possibly have affected immediately adjacent areas, indicated with relatively decreased salinity range of 5 - 7.5 mS/cm.

Moderately saline groundwater also occurs in the former Amibara settlement and Algeta farms as well as in the southern part of Melka Werer farm. Electrical conductivity is between 5 and 7.5 mS/cm.

Groundwater with EC less than 5 mS/cm account to about 13%. It is some 1900 ha, located near Melka Sadi gravity intake and downstream of Melka Werer town in the pumping stations vicinity. Areas with EC of about 2.5 and less are delineated in very close proximity to the Awash river. It shows that the groundwater salinity in these areas is highly influenced by the river-groundwater and canal-groundwater transfers.

CHAPTER SEVEN

SOIL SALINITY AND SODICITY

7.1 Introduction

Salt-affected (saline) soils generally occur in semi-arid and arid regions. Such areas are characterized by relatively low and erratic rainfall and high evaporation rate. There is limited leaching and transportation of soluble salts (Richards, 1954). Depressions filled with water can also turn into a salt-field upon evaporation.

The Middle Awash Valley is a semi-arid region with considerable irrigated agriculture along the Awash river. The problem of salinity in this region had been given attention in several studies. Substantial amount of land had been reported abandoned due to salinity and rising groundwater in the region. As discussed in previous chapters, the groundwater is generally saline and is encountered within 3m in some places. Therefore, the extent and distribution of irrigation-induced salinity needs to be investigated as excessive salts affect crop growth through reducing water availability by the action of osmotic pressure.

7.2 Classification of Salt-affected Soils

One of the widely-used classification systems of salt-affected soils is the USDA system. The indicative parameters used in the classification are electrical conductivity of the saturation extract (ECe), saturated soil paste pHe and exchangeable sodium percentage (ESP). ESP is widely used as measure of the effects of high sodium level and is defined as:

$$ESP = \frac{\text{Exchangeable Na}}{\text{CEC}} \times 100 ;$$

Where, Exchangeable Na = Extracted Na – Soluble Na; me/100g soil

CEC = Cation-exchange capacity; me/100g soil

The USDA groups of salt-affected soils as described in Richards (1954) are:

Saline

- ECe is more than 4 mS/cm
- ESP is less than 15
- pHe is usually less than 8.5
- Correspond to the *Solonchaks* of the Russian soil scientists

Saline-Alkali (also called saline-sodic)

- ECe is more than 4 mS/cm
- ESP is greater than 15
- pHe is seldom higher than 8.5
- Soils are also called *saline-sodic*

Nonsaline-Alkali (also called sodic)

- ECe is less than 4 mS/cm
- ESP is greater than 15
- pHe usually range from 8.5 and 10
- Correspond in some cases to *Solonetz* (term used by Russians)
- Soils are also called *sodic*

Soils with electrical conductivity of the saturation extract less than 4 mS/cm (dS/m) and exchangeable sodium percentage less than 15 are therefore grouped as non-saline and non-alkaline. They may also be called normal soils if their pH is not strongly alkaline.

7.3 Soil Field Survey and Chemical Analysis

Soil auger samples were collected at four depths of 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm during the field survey between April and May 2004. A total of 556 soil samples were analyzed for pHe, ECe and soluble cations at the laboratory of Werer Research Center (WRC) in May and June 2004. Out of these, 455 are surface soil samples (0-30cm) while 101 samples are samples between 30 and 120 cm.

The soil sampling sites have been spatially referenced using GPS during the survey. Sampling sites are randomly distributed, a bit influenced by the spatial configuration of the field plots, access road and canals. Average sampling density is about one sample per 33 hectares, calculated by dividing the total number of surface samples by the gross area under investigation.

The particle size distribution has been discussed when describing the texture and other physical properties of soils in Chapter 4. The soil samples were first dried on the sun and crushed.

7.4 Soil Reaction (pHe)

In diagnosing the physical and chemical properties of soils, pH measurements are important. Soil pH measurements depend upon the relative amounts of soil and water added during analysis. Measurements of pHe were made on extracts from saturated soil pastes using pH

meter. The majority of the soil samples have pH of saturation extract (pHe) greater than 7, indicating general alkaline reaction. A normal pH for soil and water ranges from 6.5 to 8.0; a pH beyond this range may result in nutritional and growth problems.

7.5 Soil Salinity Assessment

Soil salinity becomes of a concern when sufficient salts accumulate in the root zone to adversely affect plant growth. Excessive concentration of salts in the root zone results in the interference of the plants osmotic pressure.

The electrical conductivity of saturation extract (ECe) is considered as a common indicator of the total concentration of soluble salts in` soils. According to Abrol et al. (1988), measuring the electrical conductivity of a saturation extract has an advantage in that saturation percentage is directly related to field moisture range. Deci Siemens per meter (dS/m) is the unit commonly used to measure ECe of soils, which is equivalent to milli Siemens per centimeter (mS/cm).

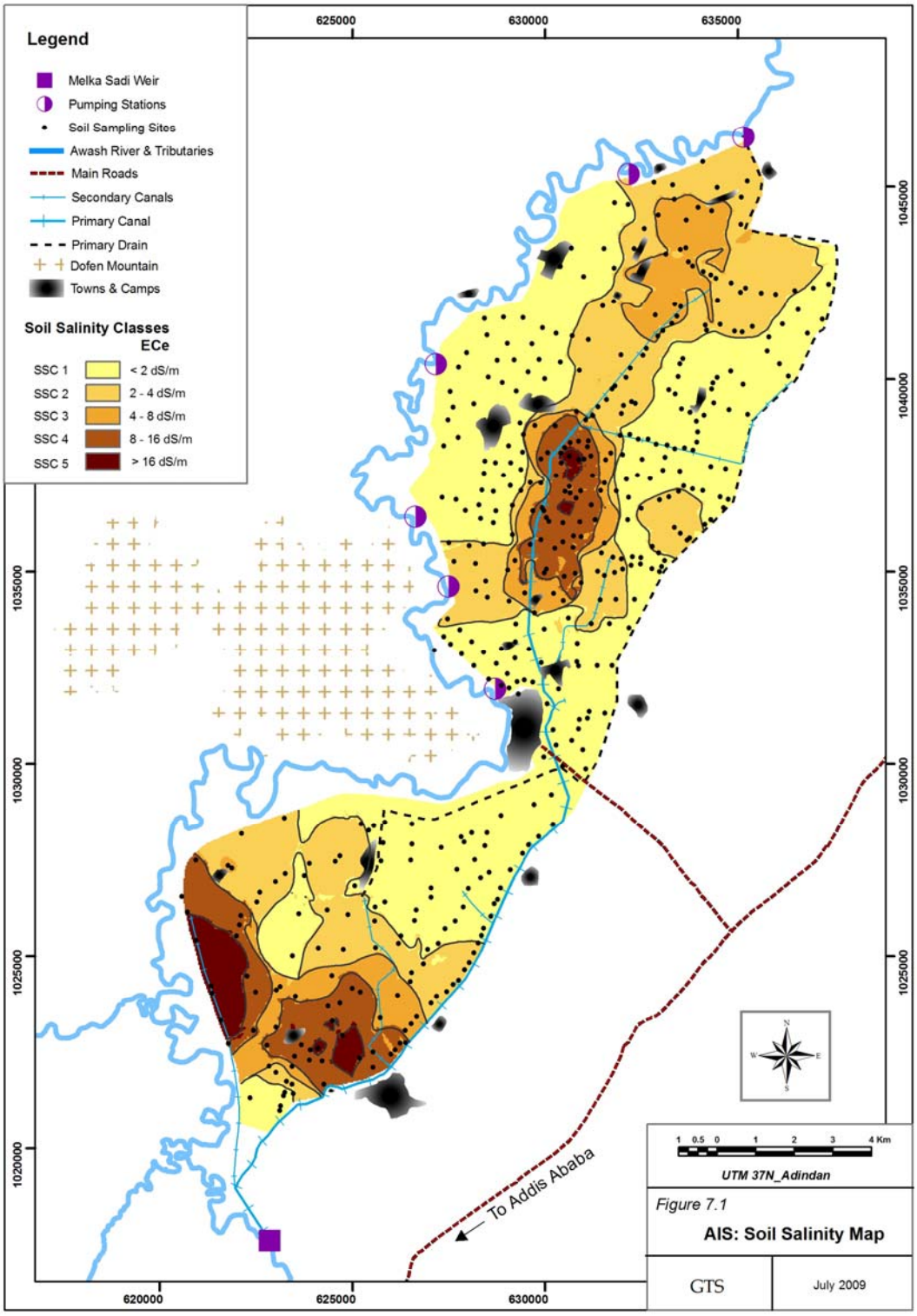
Taking the ECe values of 455 surface soils samples (0 - 30cm), a soil salinity raster map was created using preferred GIS techniques (Figure 7.1). The salinity hazard is expressed as salinity classes using ECe ranges generally recognized and reported in Abrol et al. (1988).

About 50% of the soils in AIS are non-saline (SSC 1) with ECe less than 2dS/m while about 27 % is slightly saline (ECe b/n 2 and 4 dS/m). The map shows that there is a slightly saline zone (2-4 dS/m) along the main canal in the Amibara plain. Taking ECe of greater than 4 dS/m as a rough definition of saline soils alone, it has been estimated that 23 % of AIS soils are moderately to very strongly saline - SSC 3, SSC 4 and SSC 5. Farms with soils of such classes include the former Melka Sadi banana, Melka Sadi cotton and Melka Werer cotton farms.

Table 7.1 Distribution of Soil Salinity in AIS

No.	Soil Salinity Class	Description	ECe (dS/m)	*Area (ha)	% Area
1	SSC 1	Non-saline	< 2	7600.1	49.9
2	SSC 2	Slightly Saline	2 - 4	4168.5	27.4
3	SSC 3	Moderately Saline	4 - 8	1563.3	10.3
4	SSC 4	Strongly Saline	8 - 16	1500.0	9.8
5	SSC 5	Very Strongly Saline	> 16	399.8	2.6
				15231.7	**100.0**

* refers to gross area under investigation


Legend
Melka Sadi Weir
Pumping Stations
Soil Sampling Sites
Awash River & Tributaries
Main Roads
Secondary Canals
Primary Canal
Primary Drain
Dofen Mountain
Towns & Camps
Soil Salinity Classes
ECe
SSC 1 < 2 dS/m
SSC 2 2 - 4 dS/m
SSC 3 4 - 8 dS/m
SSC 4 8 - 16 dS/m
SSC 5 > 16 dS/m
625000
630000
635000
1045000
1040000
1035000
1030000
1025000
1020000
620000
To Addis Ababa
1 0.5 0 1 2 3 4 Km
UTM 37N_Adindan
Figure 7.1
AIS: Soil Salinity Map
GTS
July 2009

Relatively elevated salinity values can generally be expected as sampling was done during the fallow period, just before pre-irrigation. Surface soils are exposed to direct evaporation during the fallow period. In places where groundwater is shallow, salts can concentrate on surface soils. Typical secondary-salinization prone areas include fields intensively irrigated for relatively longer period of time and areas in close proximity to irrigation canals.

Cotton being relatively tolerant to salinity, yield may decrease when ECe value is greater than 8 dS/m. Therefore, relative decrease in cotton yield grown in some 1900 ha may occur if salinity levels are not reduced using proper reclamation measures.

7.6 Soil Sodicity Assessment

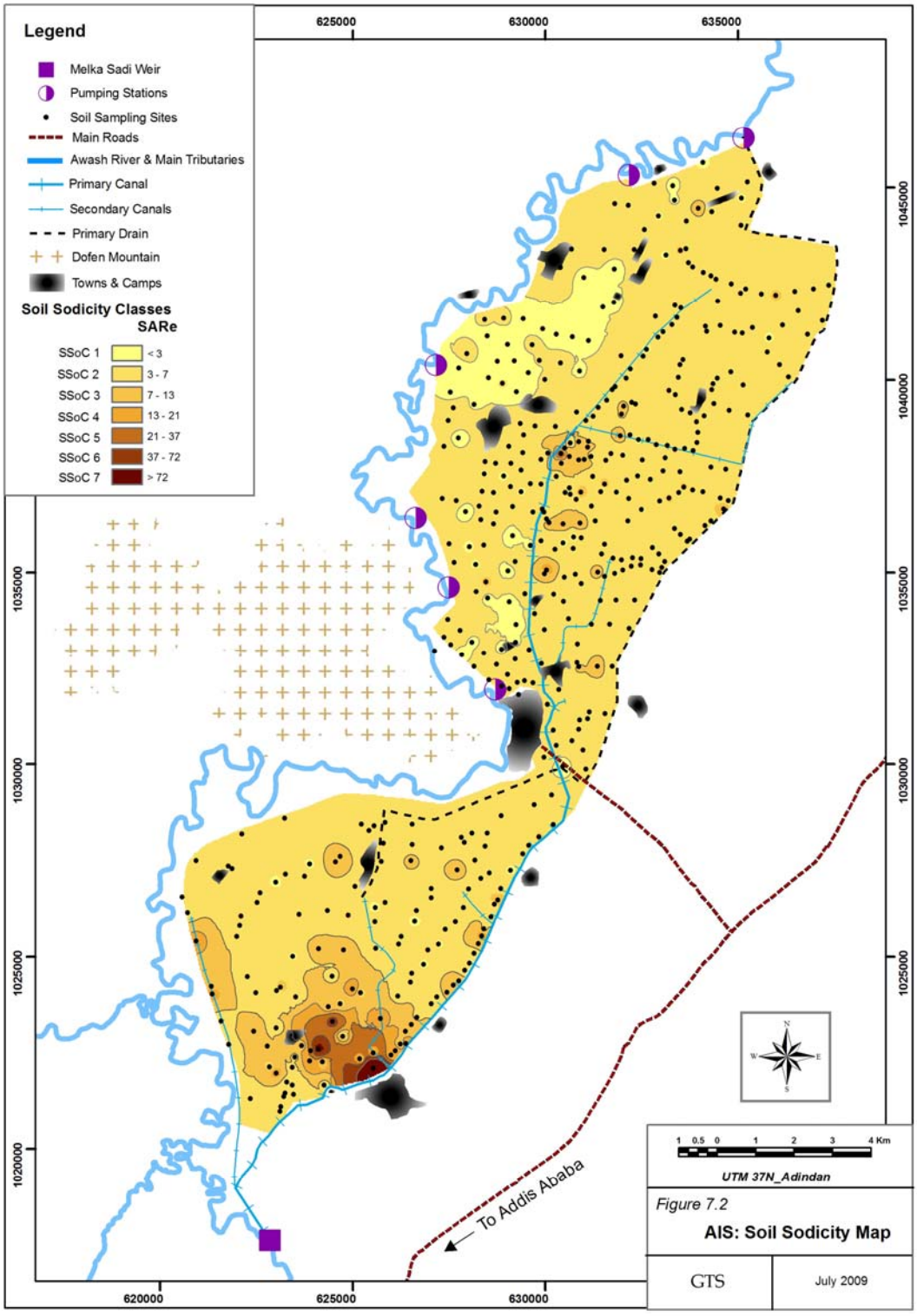
The adverse effect of sodium on some crops and soil physical condition becomes of a concern when sodium is present in the soil in significant quantities, especially in proportion to the other cations. Increased levels of sodium may result in soil clay dispersion. In doing so, soil structure may be lost and there may be reduction in infiltration and hydraulic conductivity of the soil. Surface crusting may develop forming a relatively impermeable layer. Nonetheless, soils containing increased levels of sodium and excess total soluble salts may have better physical properties.

As stated in section 7.2, exchangeable sodium percentage (ESP) is widely used to measure sodicity status of soils. The percentage value is the proportion of the exchange complex that is occupied by sodium. Sodium adsorption ratio of the saturation extract (SARe) is another parameter that has long been recognized as an index or indicator of sodicity hazard (Richards, 1954; Abrol et al, 1988). It is the proportion of water soluble sodium to calcium plus magnesium in the soil and is expressed in an equation form as:

$$SARe = \frac{(Na^{+})}{[(Ca^{2+} + Mg^{2+}) / 2]^{0.5}}$$

Where concentrations of the cations (obtained from a saturated paste soil extract) are expressed in meq/l.

For several practical reasons, SARe is currently used as a standard measure for sodicity. SARe can also be used as a fair measure of the exchangeable sodium status of soils. An empirical relationship between ESP and SARe has been developed based on experiments made in North America by the US salinity laboratory staff, which was also used for preparation of a nomogram (Richards, 1954). The practical use of this nomogram has been recommended, except for extreme conditions.


Legend
Melka Sadi Weir
Pumping Stations
Soil Sampling Sites
Main Roads
Awash River & Main Tributaries
Primary Canal
Secondary Canals
Primary Drain
Dofen Mountain
Towns & Camps
Soil Sodicity Classes
SARe
SSoC 1 < 3
SSoC 2 3 - 7
SSoC 3 7 - 13
SSoC 4 13 - 21
SSoC 5 21 - 37
SSoC 6 37 - 72
SSoC 7 > 72
625000
630000
635000
1045000
1040000
1035000
1030000
1025000
1020000
620000
625000
630000
To Addis Ababa
1 0.5 0 1 2 3 4 Km
UTM 37N_Adindan
Figure 7.2
AIS: Soil Sodicity Map
GTS
July 2009

In this study, determination of soluble cations has been carried out on saturation extracts of soil samples. The principal purpose of conducting such expensive and laborious soluble cation (Na^+, Ca^{2+} and Mg^{2+}) analyses for more than 500 samples has been to calculate sodium adsorption ratio. It can't however be more difficult and more expensive than determining ESP using traditional laboratory procedures.

The calculated SARe for 455 surface soil samples (0 – 30cm) were interpolated to create a potential soil sodicity map (Figure 7.2). The soil sodicity hazard is expressed as classes of sodium adsorption ratio. The different classes may provide implications for reclamation purposes in addition to defining roughly sodic and non-sodic soils.

Table 7.2 Distribution of Soil Sodicity in AIS

No.	Soil Sodocity Class	Description	SARe	*Area (ha)	% Area
1	SSoC 1	Non-Sodic	< 3	1252.4	8.2
2	SSoC 2	Very Slightly Sodic	3 - 7	12297.7	80.7
3	SSoC 3	Slightly Sodic	7 - 13	1207.0	7.9
4	SSoC 4	Moderately Sodic	13 - 21	223.6	1.5
5	SSoC 5	Strongly Sodic	21 - 37	170.5	1.1
6	SSoC 6	Very Strongly Sodic	37 - 72	48.8	0.3
7	SSoC 7	Extremely Sodic	> 72	31.7	0.2
			Total	**15231.7**	**100.0**

* refers to gross area under investigation

Non-sodic soils with SARe of less than 3 cover about 8% of AIS. Referring to Sogreah (1965), these areas are mapped as vertisols. About 80% of the area has been mapped as soils of class SSoC2 – very slightly sodic.

It has been suggested in section 7.2 that an ESP value of 15 is taken as a rough (not sharp) boundary between sodic and non-sodic soils. SARe 13 is comparable to an ESP value of 15. Using SARe value of 13 as a susceptibility boundary to sodicity, it has been estimated that about 3% of the total area under investigation as soils having potentially sodicity related problems (see Table 7.2). It can be seen in the map that substantial part of soils of the former Melka Sadi banana farm have sodicity problems, mapped as moderately – extremely sodic (SSoC 4 - 7). However, as it will be discussed later, checking this area revealed that the soils also contain excess soluble salts (ECe greater than 4 dS/m).

Cotton is regarded as relatively tolerant to sodicity. According to Bower (1959) cited in Booker Tate (1991), stunted growth usually due to adverse physical conditions of soil

however can occur at an ESP value more than 40. A sample PK1 in area designated as extremely sodic has the highest SAR value (see annex). In this area, poor physical soil conditions arising from sodicity problems may restrict root growth and may make tillage difficult. Soils with high amount of sodium occur rarely in places other than Melka Sadi.

7.7 Salt-affected Soils and Their Reclamation

Electrical conductivity and sodium adsorption ratio of spatially referenced soil samples were used to create the above two most important maps – the soil salinity (hazard expressed as ECe) and the soil sodicity hazard (expressed as SARe). Re-classifying these two raster maps and combining them were carried out on well-defined GIS grids to produce Figure 7.3, a distribution of salt-affected soils map.

Referring to section 7.2, salt-affected soils are generally grouped as saline, sodic and saline-sodic. For this specific study, sodium adsorption ratio (SARe) is conveniently used as a substitute for ESP. Table 7.3 gives the soils groups with their corresponding areas and calculated area percentages.

Table 7.3 Distribution of Salt-affected Soils in AIS

No.	Soil Group	ECe (dS/m)	SARe	*Area (ha)	% Area
1	Non-saline - Non-sodic	< 4	< 13	11725.1	77.0
2	Saline	> 4	< 13	3028.2	19.9
3	Sodic	< 4	> 13	13.3	0.1
4	Saline - Sodic	> 4	> 13	465.1	3.0
				15231.7	**100.0**

***** refers to gross area under investigation

When dealing with salt-affected soils and crop growth, a clear picture can be sought by taking into consideration a number of factors like textural variations, distribution of salts in the profile, type of crop, type of salt (composition), water-logging, etc. Detailed study of soils chemical composition is beyond the scope of this study. Reported full chemical analysis of soil sample results can be found in previous studies such as Halcrow (1982), Heluf Gebrekidan (1985), etc.

From Table 7.3, it can be deduced that about 23% of AIS soils are salt-affected soils. Considerable portions of the former Melka Sadi banana farm and Melka Sadi farms are mapped as saline or saline-sodic. These areas coincide with areas where the current groundwater level is close to surface (see Figure 5.5).

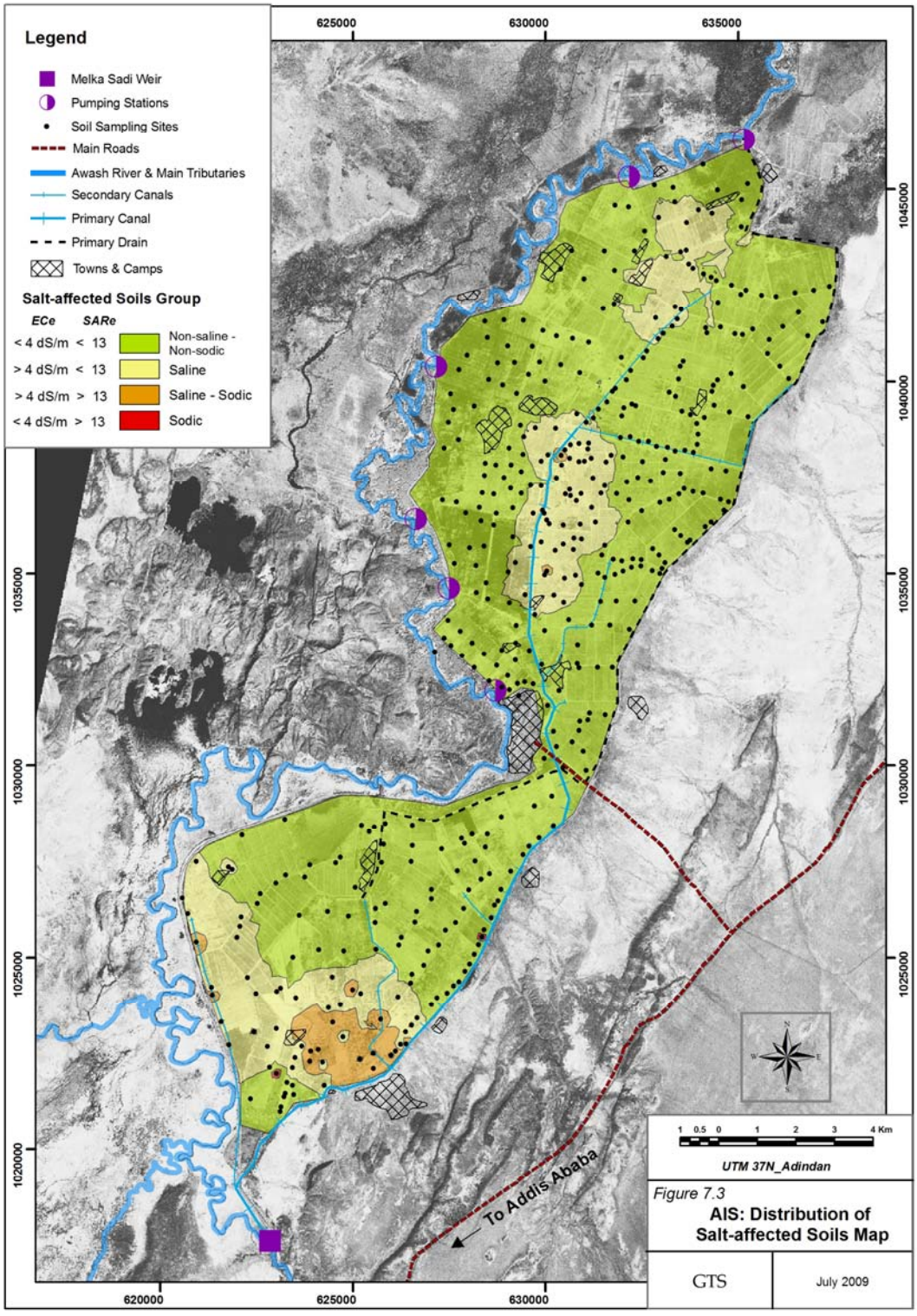
With 19.9% spatial coverage, saline soils (ECe > 4 dS/m and SARe < 13) form the predominant type of salt-affected soil group in AIS. The surface soils samples grouped as saline have pHe values less than 8.5. Checking the available saline sub-soil samples collected from depths between 30 and 120 cm, the pHe is found to be even less than 8. Occurrence of some samples with measured pHe values closer to 7 may indicate the presence of neutral salts within the root zone. In some of these areas, whitish -salt crystals on the surface soils were observed during the filed survey.

On the other hand, sodic soils (ECe < 4 dS/m and SARe > 13) of the project area occur patchily covering a very limited area. The influence of sodicity on structure and permeability of soil has been mentioned in previous section. This may indicate that where surface soil salinity is low, the dominance of sodium over the divalent cations (calcium and magnesium) is not currently prevalent.

Saline-sodic soils generally form as a result of the combined processes of salinization and alkalization (Richards, 1954). About 3% of the project area is mapped as saline-sodic (ECe > 4 dS/m and SARe > 13). Within this area, there are soil sampling points that were checked for their pHe values (soil-reaction). Except for few samples, they were found to have pHe values less than or equal to 8.5. These soils may have relatively better physical properties comparable to those of saline soils since they may not be currently strongly alkaline. Upon leaching of excess soluble salts for some time, they may become strongly alkaline and posses unfavorable physical property similar to sodic soils.

Sample from a small private farm (locally known as Keriye's farm) adjacent to the former Melka Sadi banana farm is an exceptional saline-sodic sample with pHe of about 10.5. The SARe of the sample is the highest value (over 200). Values of pHe slightly decrease with depth but still above 9.2. It was observed during the survey that part of this farm's soil has poor structure with tillage problems.

Currently, about three-fourth of the study area is estimated to be non-saline and non-sodic soils (ECe < 4dS/m and SARe < 13). Soil salinity and sodicity are dynamic parameters. Figure 7.1 & 7.2 portrays the spatial distribution of the current surface soil salinity (ECe) and sodicity (SARe) of the study area. If salts are not leached down and drainage is not provided soon, the soils will be more affected by salinity or/and sodicity. There will also be change in the distribution of salt-affected soils spatially.


Legend
Melka Sadi Weir
Pumping Stations
Soil Sampling Sites
Main Roads
Awash River & Main Tributaries
Secondary Canals
Primary Canal
Primary Drain
Towns & Camps
Salt-affected Soils Group
ECe SARe
< 4 dS/m < 13 Non-saline - Non-sodic
> 4 dS/m < 13 Saline
> 4 dS/m > 13 Saline - Sodic
< 4 dS/m > 13 Sodic
625000
630000
635000
1045000
1040000
1035000
1030000
1025000
1020000
620000
To Addis Ababa
1 0.5 0 1 2 3 4 Km
UTM 37N_Adindan
Figure 7.3
AIS: Distribution of Salt-affected Soils Map
GTS
July 2009

It is essential to recognize that the maps are prepared from point observations with laboratory-determined attributes. Field observations of soil properties (e.g. soil structure), presence of salt crystals, poor or stunted crop growth are some of the important parameters that can be taken as validation for the analysis results. Furthermore, historical yields of some of the known salt-affected field plots in those areas should be investigated.

Reclamation of saline soils involves removal of soluble salts from the root zone. It has been stated in Chapter 4 that it is essential to consider an additional amount of irrigation for leaching salts. It can be managed by having pre-irrigations in the saline areas including areas where ECe is greater than 2 dS/m in order to avoid further salinity build-up. On the other hand, gypsum is required for the saline-sodic soils since calcium is necessary to replace sodium. This followed by leaching of sodium below the root zone.

The Awash river during high flow period can be considered as a potential source of calcium. During this season, the water is of Na-Ca-HCO3 type.

Increased SARe can potentially cause permeability problems for soils containing significant amount montmerillonite and illite. Therefore, it is important to consider clay mineralogy when dealing with irrigation water quality.

It should be stressed here that adequate drainage should be provided prior to salt-leaching and/or amending the soil with gypsum. Referring to section 5.5, the groundwater is shallow (within 3m) in about 30% of AIS and encountered between 3-4 m depths in about 50% of AIS. Furthermore, currently the sub-surface drainage facilities serve some 3820ha which does not fully cover areas delineated as GWD1 (within 3m) (see Figures 4.10 & 5.5).

Evaporation greatly exceeds precipitation in Amibara area that despite the installation of sub-surface drainage, it is likely that there will be upward movement of groundwater and solute during the fallow period. Therefore, salts that accumulate every season in the surface soils need to be leached down the root zone by applying pre-irrigation. Geremew Eticha et al. (1994) suggested keeping farmlands under continuous cropping (wet) to avoid movement of salt to the surface from shallow groundwater in course of alternate wetting and drying.

In addition to all these, soil fertility may also be another parameter that should be considered if a soil and crop management plan is to be prepared in conjunction with salinity and sodicity control.

Conclusion and Recommendation

The Awash river basin comprises the north-western and south-eastern highlands and the rift valley. The highlands are mainly Tertiary basalts while Quaternary volcanic rocks (mainly basaltic flows, pyroclastics and silicic domes) and alluvial deposits (mainly fluvial, colluvial and lacustrine) characterize the rift.

Settled agriculture is a mode practiced on Dega and Woina Dega highlands of the basin with rain-fed croplands. The Awash valley, on the other hand, is semi-arid (Kolla) with quite a number of medium- to large-scale irrigation schemes along the Awash river.

The highlands of the basin receive considerable rainfall - mean annual rainfall greater than 850mm; exceeding 1400mm in certain places. The north-western highlands are mainly dissected escarpments of high to moderate relief hills and mountains that in general favor runoff and concentrate flows into streams. The amount and pattern of tributary flows draining the highlands are influenced by climate, particularly rainfall. Monthly average stream flow peaks tend to coincide with the patterns of rainfall stations installed on the highlands.

In contrast, the rift receives moderate rainfall (about 850 - 550mm) in the upper valley to less than 300mm in the lower plains. Potential evapotranspiration is relatively higher in the valley than on the highlands, ranging from 1550 to 2150mm/year. In such case where PET is on average much higher than rainfall, recharge from the available surface water resource i.e. from the Awash river becomes of importance in the valley.

The Awash river water balance was computed by dividing mainstream Awash into two reaches: Koka-Metahara and Metahara-Tendaho. The period considered is five years (July 1998 to June 2003), so as to allow for current level of irrigation development. This means that the amount of irrigation water abstracted by medium- to large-scale irrigation farms during this period has been taken into account. Return flows from the irrigation schemes have been incorporated as percentages of the total diverted flows. Surface runoff contributions from tributaries and riverside sub-catchments have been estimated by analyzing stream flow data and making use of established relationships between runoff, catchment area and rainfall for the same period. By dividing the channel into several segments and taking mean PET rate at selected stations, channel evapotranspiration was calculated.

The results for the two reaches show that the Awash river is generally influent. Transmission loss of some 2.1 BCM and 6.8 BCM for the reaches Koka-Metahara and Metahara-Tendaho

have been obtained for the same period. These total transmission losses, however, include potential indirect recharge as well as loss due to over-bank flooding and subsequent evaporation. Located in the middle part of the Metahara-Tendaho reach, considerable loss due to potential evapotranspiration occurs at Gedebassa swamp area with an estimated value of about 500 MCM/yr.

Potential sites that favor transmission loss are sub-reaches with highly permeable alluvial and fractured volcanic river beds plus parts of the valley where groundwater tables are generally deeper, i.e. at lower elevations than the Awash river. Nonetheless, within these two long reaches, there are intermediate reaches that may reveal that the Awash river is also effluent. For example, major irrigation areas with shallow groundwater tables in the upper and middle valleys feed the Awash river. In the sub-reach immediately downstream of Koka, the Awash river also receives groundwater inflow from Koka reservoir leakage.

In evaluating the various components of the water balance, due attention was given to current resource availability conditions and irrigation developments in the Awash basin. Considerable amount of water irrigation is supplied to the upper valley schemes, accounting to about 60% of the overall total abstractions (815 MCM/year). Wonji/Shoa and Metahara sugar estates as well as Merti Jeju and Nura Hera farms grow perennial crops (sugarcane and tree fruits) in large areas that require irrigation throughout the year. With considerable amount of irrigable lands abandoned in the middle and lower valleys, major abstractions are made to the Amibara Irrigation Schemes.

Surface irrigation is a method widely practiced in the Awash valley. For semi-detailed assessment of effects of surface irrigation farms on water and soil resources, the Amibara Irrigation Schemes have been selected. The potential evapotranspiration (reference crop evapotranspiration) estimated at Melka Werer is 1970mm using Penman Monteith method, which is more than three times the average rainfall depth (542mm for AIS).

Cotton water requirements have been estimated using CropWat model. Taking effective rainfall into consideration, the result obtained is an average net irrigation requirement of 71cm for the season. Modelled irrigation scenarios have shown that 5 to 7 irrigations per growing season are required, with total net depths of 60-72 cm for staggered cotton planting plots. To this amount, an additional pre-irrigation of some 22cm is required for leaching purpose.

Evaluations of surface irrigation practice and water management at Amibara included key issues at system- and farm-level. The infrastructure of AIS is relatively better than or

comparable to other major farms in the valley as it incorporates networks of canals, drains, and water regulating and measuring facilities. Nonetheless, facilities vary within the AIS; the Melka Sadi- and Melka Werer-cotton and the former Melka Sadi banana farms are provided with better infrastructure than the other farms.

Currently measurements of the supplied water are made at the primary offtakes, mainly on the primary canal but not at the project headworks. Furthermore, measurements of abstractions for the pump schemes could not be made, as water meters are either not available or not functional. Operational losses due to direct rejections are management issues between the Awash Basin Agency (ABA) and the receiving entities (farm owners).

Siltation is another major problem in Amibara that reduces the capacity of the canals. Annual de-silting operations, albeit limited to the main canal, have resulted in additional notable works and expenses to ABA. The drainage canals, however, are not timely maintained, resulting in still water to stay for longer time than is necessary, thereby distracting effective drainage and contributing to groundwater level rise as well. With respect to catchment erosion and sediment inflow to streams, integrated watershed management should be taken into consideration that essentially incorporate soil and water conservation measures.

Taking into consideration the calculated mean annual irrigation water use for the gravity supplied schemes (i.e. about 14.1cm or 14.1 x 10^3 m^3/ha), the computed net irrigation requirement, and conveyance efficiency of 85%, the overall efficiency of AIS has been estimated at 43% (say 40-45%). This shows that more water has been abstracted than is necessary, resulting in significant amounts of recharge through percolation and canal seepages.

Systematic analysis of groundwater levels have been performed to investigate rising groundwater levels in AIS. Hydrograph analysis based on piezometers data have shown that recharge from surface irrigation at various farms have occurred in the 70s - 90s, with a rate of rise ranging from 0.3 to over 1m/yr. While annual groundwater levels tend to vary with the annual average irrigation amounts supplied to major farms, seasonal level fluctuations correspond to seasonal cotton irrigation regimes influenced by seasonal rainfall and stream flow patterns.

The groundwater flow analysis has indicated: the groundwater has an outlet to the Awash river; there is groundwater inflow to the Melka Sadi plain from the relatively elevated adjacent areas and the Awash river; and general groundwater flow occurs from Melka Sadi area to Amibara plain and further north towards Angelele plain likely following regional conditions.

In addition to these, the irrigation canals also affect the groundwater in that equipotential flow lines tend to align along the elevated main canal downstream of Melka Werer, while a kind of groundwater mound with very low gradient have developed on the right canal bank. The groundwater contours are also affected by a major secondary canal in Melka Sadi area.

The produced depth to groundwater map has shown that currently the groundwater is within 3m in about one-third of AIS - that include considerable parts of the former Melka Sadi banana, Melka Sadi- and Melka Werer-cotton farms. In about 50% of AIS, the annual average groundwater level is between 3 to 4m.

The alluvial aquifers in Amibara irrigated areas receive recharge from rainfall, surface runoff and irrigation, while the latter is responsible for the rising groundwater levels. The alluvial sediments are not capable of fully draining the recharges from successive irrigations to Awash river and adjacent plains. This is due to low hydraulic conductivities of the fluvial deposits and occurrences of relatively impermeable layers of very low conductivity. With such shallow water table prevailing in AIS, evaporation has become one of the major outflow components other than groundwater outflow.

While tasks involved in investigating rising groundwater levels in Amibara have made available such insights to the past and current situations in Amibara area, the hyrdo-chemical investigations have provided the following valuable information:

With moderate salinity and low sodicity, the Awash river is considered suitable for irrigation; yet the salinity of the Awash river increases downstream from upper to lower valley. The seasonal variations in Awash river salinity become important during the low flow period as the relative contribution of saline thermal springs and groundwater inflow from irrigated areas increase during this period in Amibara area. Electrical conductivities of drainage canal samples are relatively higher than the irrigation canals.

The groundwater is generally saline with 85% of AIS (EC greater than 5 mS/cm); 30% is highly saline (EC > 10 mS/cm). As evidenced from full chemical analysis of piezometer samples, the highly saline groundwater is of Na-Cl and Na-Cl-SO4 types while bicarbonate becomes relevant to certain extent for groundwater with EC less than 10mS/cm. The relative dominance of sodium over calcium decreases in piezometers located close to either the Awash river or the irrigation canals. In this respect, it is noteworthy that the Awash river is generally of Na-Ca-CO3 type which changes to Na-HCO3-Cl during low flow period.

Assessments of soil salinity and sodicity make up the last but invaluable investigations of this study. Bulk surface soils samples (some 556 in no.) have been collected from Amibara farms during the fallow period (non-irrigation season). The majority of the soil samples have pHe greater than 7, indicating general alkaline reaction. It has been mapped that 23 % of AIS soils are generally saline with ECe greater than 4dS/m while about 12% of AIS soils are strongly to very strongly saline (ECe greater than 8 dS/m). In addition, about 3% of AIS soils have been mapped as potentially having sodicity-related problems with SARe greater than 13. Combining these two gave 20% saline soils and 3% saline-sodic soils.

Typical secondary-salinization condition, which is essentially irrigation-induced, is the case in Amibara. Surface soils are exposed to direct evaporation during the fallow period. In places where groundwater is shallow, salts concentrate on surface soils. Leaching of salts below the root zone is required in order to avoid yield losses with eventual abandonment of irrigable lands. It can be done by considering an additional amount for leaching during pre-irrigation. Gypsum may be required for the saline-sodic soils in order to replace sodium with calcium, followed by leaching down of the sodium below the root zone.

Nonetheless, the shallow groundwater table that has resulted from irrigation recharge can hinder effective leaching. Currently, only about 30% of AIS is served by the sub-surface drainage facility. Although parts of the former Melka Sadi banana and Melka Sadi cotton farms have such facilities, the Melka Werer farm where the groundwater is encountered within 3m does not possess sub-surface drainage.

The channel water balance has greatly helped in assessing the current resource availability conditions with recent level of irrigation developments. What future works need is to model the basin by analyzing future levels of irrigation development and the environment. Appropriate considerations need to be given to future irrigation expansions in the upper, middle and lower valleys, as well as in the lower plains. Initially proposed during the Survey of the Awash River Basin in the mid-60s (Sogreah 1965), Kessem and Tendaho dams are now under construction, nearing completion. They are intended to supply irrigation to the large-scale farm expansions in Amibara area and the lower plains respectively. In addition to these are the proposed expansions of Wonji/Shewa and Metahara sugar plantations in the vast plains of the upper and middle valleys.

Quality flow data are required for relatively accurate results; therefore additional gauging stations are required on Awash river and its tributaries. Currently, stations on tributaries are concentrated along the main highway from Addis Ababa to Woldia, located on the upstream reaches. Having additional stations downstream (close to confluences with the Awash) for

few major tributaries can provide better estimations on the amount of inflows to the Awash river. On mainstream Awash, stations are required before and after Gedbassa swamp, and upstream of the Tendaho reservoir. Site selection for gauging stations need to consider river segments with stable river banks. Attention however needs to be given to all existing stations as timely maintenance and updating of flow curves is essential.

The proposed projects will definitely change the water balance and the existing hydrogeoecological environment if fully or partly implemented. Huge abstractions made by existing major irrigation schemes in the upper valley have been affecting the available surface water resource, indicating that additional schemes should consider irrigation methods with higher efficiencies. Otherwise, with development of the proposed upper valley schemes, the required flow at Melka Sadi intake (for example) will be markedly insufficient. Kessem river will not directly join mainstream Awash, which would likely affect the amount of available flow downstream for the pump-schemes of Amibara if regulated releases are not appropriately designed. It may also affect the dilution effect with respect to the required salinity of the Awash river for downstream farms during certain flow periods, indicating the need to calculate dilution factors in the future. The swamps and lakes in the lower plains will also be affected if minimum amount of releases are not envisaged.

Maximum effort should be done in increasing the overall irrigation efficiency of the existing farms. Better irrigation methods, irrigation structures, monitoring and managerial skills levels should be incorporated. As for irrigating methods, irrigation efficiency greater than 70 % could be achieved by using pressurized irrigation. Sprinkler irrigation is commonly practiced in many countries for sugarcane and cotton plantations. In Ethiopia, experiences could be shared from Fincha sugar plantation (located within the Abay basin) and be of great importance for the medium- to large-scale farms in the Awash basin. Regardless of its initial and operating costs, drip irrigation method may require special attention due to the heavy sediment load associated with the Awash river.

In this regard, securing access to electrical power is necessary for effecting the said irrigation techniques should be given proper consideration. And focus needs to be made on identifying various energy alternatives, since, as has been observed in some farms, the use of such means as diesel-driven pumps entails substantial financial expenses.

With respect to managing farm-scale irrigation requirements, the model CropWat allows user-defined irrigation events plus the option to add adjustments (like daily rainfall events) to calculate soil moisture deficit (SMD). This can provide a flexible tool for monitoring soil moisture during the growing season.

With regards to monitoring of surface water/groundwater levels, salinity and other irrigation-related problems, some of the important issues that should be taken into consideration during formulation of monitoring programs include selection of monitoring types, scales, sites and frequencies. For example, appropriate monitoring sites should be chosen for better understanding or evaluation of the general hydrogeology (sub-regional to local), the natural and anthropogenic effects, the type of groundwater flow systems (shallow, deep, thermal springs), the most important hydrologic and hydro-chemical components/parameters (temporal/seasonal and spatial variations), etc.

Network of piezometers or observation wells specifically installed for monitoring proposes are lacking in all irrigation farms except Amibara. Existing wells and boreholes in some farms could provide sites for regular or intermittent monitoring of groundwater levels and salinity conditions in areas of interest. Besides these, improving the existing monitoring system in the valley should also be given attention. For example, out of some 70 piezometers installed in AIS and its immediate environs, more than 20 are currently non-functional. It has been understood from field visit observations and discussions with local farm managers that some of the piezometers were destroyed and misaligned by tractors during field operations (ploughing, leveling, furrowing, etc.). In few spots, piezometer caps were removed and deliberately filled with stones.

In parts of the valley, where such network of boreholes is inadequate or not available, piezometers or observation wells should be installed at selected places. It has been recommended in Halcrow (1989) that an observation density of 1 piezometer per 100 ha is needed in irrigated areas with high and rising water tables, while in essence installation of sub-surface drainage may be considered if rising water tables reach within 3 meters. Nonetheless, in areas where groundwater tables are lower with insignificant rising trend, it is suggested that a density of 1 observation well per 400 ha should be made available.

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Annex 1a Rainfall Data for Selected Stations

Stations		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	AM	RM
Upper Basin															
Addis Ababa Observatory (1961-2003), mm		16.1	38.6	68.0	88.1	83.6	130.2	261.9	278.3	171.5	37.3	9.3	9.6	1192.5	99.37
	RC	0.16	0.39	0.68	0.89	0.84	1.31	2.64	2.80	1.73	0.38	0.09	0.10		
	No of Years	43	43	43	43	43	43	43	43	43	43	43	42		
North-western Highlands															
Shola Gebeya (1962-2003), mm *		10.0	25.8	48.0	66.1	47.8	62.0	272.4	293.7	95.6	27.5	8.5	4.0	961.5	80.12
	RC	0.12	0.32	0.60	0.83	0.60	0.77	3.40	3.67	1.19	0.34	0.11	0.05		
	No of Years	40	41	42	42	41	42	42	41	42	42	40	41		
Aleltu (1974-2003), mm *		17.3	18.1	66.9	64.9	49.9	96.5	297.6	304.0	114.5	22.0	3.8	2.3	1057.8	88.15
	RC	0.20	0.21	0.76	0.74	0.57	1.10	3.38	3.45	1.30	0.25	0.04	0.03		
	No of Years	27	29	29	30	29	29	29	29	29	28	29	28		
Alyu Amba (1962-2003), mm		46.8	71.8	93.7	102.5	74.4	37.7	160.2	233.7	108.5	55.2	24.0	34.2	1042.7	86.89
	RC	0.54	0.83	1.08	1.18	0.86	0.43	1.84	2.69	1.25	0.63	0.28	0.39		
	No of Years	36	37	38	37	37	40	40	39	37	36	38	37		
Ankober (1962-2003), mm		62.2	63.7	148.0	160.7	81.2	67.5	289.0	350.4	174.7	102.5	73.5	46.9	1620.3	135.03
	RC	0.46	0.47	1.10	1.19	0.60	0.50	2.14	2.60	1.29	0.76	0.54	0.35		
	No of Years	21	23	23	24	22	23	24	24	24	24	23	23		
Shoa Robi (1963-1994), mm		46.8	70.9	93.2	126.4	69.4	21.8	164.5	220.2	96.5	38.0	25.9	25.2	998.7	83.22
	RC	0.56	0.85	1.12	1.52	0.83	0.26	1.98	2.65	1.16	0.46	0.31	0.30		
	No of Years	30	31	31	29	29	31	32	32	32	32	30	30		
Efeson (1986-2003), mm		43.1	53.7	100.8	109.7	54.3	19.0	212.8	272.1	103.3	49.5	18.5	27.1	1064.0	88.67
	RC	0.49	0.61	1.14	1.24	0.61	0.21	2.40	3.07	1.16	0.56	0.21	0.31		
	No of Years	16	16	16	16	17	17	16	17	17	17	17	17		
Kara Kore (1962-2003), mm		47.6	59.0	80.7	116.4	73.9	34.0	249.1	319.9	125.4	52.3	27.4	34.0	1219.7	101.64
	RC	0.47	0.58	0.79	1.15	0.73	0.33	2.45	3.15	1.23	0.51	0.27	0.33		
	No of Years	39	39	41	39	38	39	39	39	39	40	39	39		
Jara (1962-2003), mm		25.6	43.5	69.0	111.9	63.5	34.8	232.2	283.8	136.6	51.9	22.7	29.0	1104.5	92.04
	RC	0.28	0.47	0.75	1.22	0.69	0.38	2.52	3.08	1.48	0.56	0.25	0.32		
	No of Years	39	39	40	38	38	40	39	39	39	38	38	36		
Majete (1962-2003), mm		40.7	52.1	82.0	105.5	71.8	34.2	240.5	304.1	113.0	49.0	30.4	28.4	1151.9	96.00
	RC	0.42	0.54	0.85	1.10	0.75	0.36	2.51	3.17	1.18	0.51	0.32	0.30		
	No of Years	39	39	39	39	38	37	40	40	40	40	40	40		
Kombolcha (1961-2003), mm		26.1	35.8	74.9	97.1	62.1	31.8	251.0	254.7	109.9	43.1	22.1	20.4	1029.0	85.75
	RC	0.30	0.42	0.87	1.13	0.72	0.37	2.93	2.97	1.28	0.50	0.26	0.24		
	No of Years	43	43	43	43	43	43	43	43	43	43	43	43		
Wuchale (1962-2003), mm		43.3	55.7	96.4	113.8	87.6	35.1	254.3	286.1	107.6	52.6	36.4	41.9	1210.7	100.90
	RC	0.43	0.55	0.96	1.13	0.87	0.35	2.52	2.84	1.07	0.52	0.36	0.42		
	No of Years	38	39	39	41	41	41	41	40	41	40	40	41		
Arsi Highlands															
Tinsae Birhan (Abomsa) (1982-2003), mm **		38.0	55.8	105.3	91.2	67.0	54.4	151.5	165.7	109.0	83.6	16.1	16.3	953.7	79.47
	RC	0.48	0.70	1.32	1.15	0.84	0.68	1.91	2.08	1.37	1.05	0.20	0.20		
	No of Years	17	17	17	17	17	15	17	17	18	16	17	17		

AM: Annual Mean; RM: Rainfall Module; RC: Rainfall Coefficient; * Stations on the Highlands of Kesem River; ** Station on the Highlands of Arba River

Annex 1b Rainfall Data for Selected Stations

Stations		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	AM	RM
Rift Valley															
Nura Hera (1977-2003)		25.8	34.4	52.1	49.9	27.0	32.8	116.8	135.6	42.8	41.3	4.1	10.6	573.3	47.78
	RC	0.54	0.72	1.09	1.04	0.56	0.69	2.45	2.84	0.90	0.87	0.08	0.22		
	No of Years	17	18	19	21	20	19	20	20	20	19	18	17		
Metehara (1985-2003)		8.3	31.7	48.7	47.1	30.8	26.7	119.7	118.3	42.4	23.3	2.7	7.4	507.1	42.26
	RC	0.20	0.75	1.15	1.12	0.73	0.63	2.83	2.80	1.00	0.55	0.06	0.18		
	No of Years	19	19	19	19	19	19	19	19	19	19	19	19		
Awash (1978-2003)		22.7	40.1	66.3	61.6	53.1	28.9	125.5	132.2	61.3	30.2	14.0	13.2	649.1	54.09
	RC	0.42	0.74	1.23	1.14	0.98	0.53	2.32	2.44	1.13	0.56	0.26	0.24		
	No of Years	25	25	25	25	24	25	23	24	25	24	24	24		
Melka Werer (1970-2003)		16.4	36.7	70.8	61.2	29.6	22.4	111.8	121.8	49.4	26.1	11.2	4.4	561.7	46.81
	RC	0.35	0.78	1.51	1.31	0.63	0.48	2.39	2.60	1.05	0.56	0.24	0.09		
	No of Years	34	34	34	34	34	34	34	33	33	33	33	34		
Gewane (1963-2003)		10.7	36.8	64.0	41.7	35.0	10.9	92.2	102.5	35.6	15.7	6.4	7.5	459.2	38.27
	RC	0.28	0.96	1.67	1.09	0.91	0.29	2.41	2.68	0.93	0.41	0.17	0.20		
	No of Years	34	34	34	33	35	34	32	30	27	32	32	33		
Mile (1962-2003)		6.8	17.3	37.9	38.0	11.8	5.3	65.9	90.5	25.9	15.0	3.3	5.9	323.5	26.96
	RC	0.25	0.64	1.41	1.41	0.44	0.19	2.44	3.36	0.96	0.56	0.12	0.22		
	No of Years	39	40	39	40	40	38	38	40	40	39	39	37		
Tendaho (1962-1985)		4.7	17.2	23.0	28.2	6.4	7.3	38.7	47.9	16.8	8.8	2.2	4.5	205.7	17.14
	RC	0.27	1.00	1.34	1.64	0.37	0.43	2.26	2.80	0.98	0.52	0.13	0.26		
	No of Years	17	16	18	17	18	18	19	20	20	19	17	18		
Assaita (1962-2003)		4.2	6.4	14.0	17.5	10.2	3.9	33.2	38.3	13.8	6.7	5.5	2.1	155.7	12.97
	RC	0.32	0.50	1.08	1.35	0.79	0.30	2.56	2.95	1.06	0.51	0.42	0.16		
	No of Years	30	30	30	30	29	30	29	31	31	32	32	32		

AM: Annual Mean; RM: Rainfall Module; RC: Rainfall Coefficient

Annex 2a Potential Evapotranspiration (PET) for Selected Stations

Awash Valley (Rift Valley)

Wonji

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Max Temperature (°C)	26.5	27.6	29.2	29.1	30.2	29.4	26.2	25.9	26.9	27.6	26.5	26.2	27.6
Min Temperature (°C)	11.0	12.8	14.6	14.8	15.0	16.1	15.8	15.5	14.8	11.2	10.2	10.1	13.5
Wind Speed @ 2m (m/s)	1.32	1.26	1.25	1.12	1.11	1.52	1.61	1.28	0.84	0.97	1.26	1.36	1.24
Average Relative Humidity (%)	54	55	54	57	55	57	68	72	70	58	54	56	59
Sunshine Duration (hrs)	8.6	8.2	8.4	8.0	8.7	8.4	6.8	6.8	7.3	8.7	9.2	9.0	8.2
PET (mm/day)	4.04	4.31	4.75	4.61	4.73	4.78	4.08	3.96	3.98	4.20	4.12	3.96	4.29
PET (mm/month)	125.24	120.68	147.25	138.30	146.63	143.40	126.48	122.76	119.40	130.20	123.60	122.76	1566.7

Nura Hera

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Max Temperature (°C)	29.1	30.3	32.1	32.2	33.8	34.3	31.3	30.5	31.5	31.4	29.9	29.0	31.3
Min Temperature (°C)	12.3	14.5	15.7	17.0	17.3	19.3	17.7	17.7	17.4	14.6	12.4	11.9	15.6
Relative Humidity Average	54	56	55	56	49	48	58	63	60	51	50	54	54
Wind Speed (m/s)	1.6	1.6	1.6	1.6	1.9	2.9	3.2	2.5	1.7	1.5	1.5	1.5	1.9
Sunshine Duration (hrs)	8.8	8.5	8.2	7.4	9.0	7.4	7.0	7.4	7.5	8.6	8.8	8.8	8.1
PET (mm/day)	4.52	4.85	5.26	5.16	5.91	6.50	5.83	5.30	5.05	5.03	4.62	4.32	5.20
PET (mm/month)	140.12	135.80	163.06	154.80	183.21	195.00	180.73	164.30	151.50	155.93	138.60	133.92	1897.0

Metahara

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Max Temperature (°C)	31.2	32.8	34.3	34.8	36.3	36.8	33.1	32.3	34.0	33.8	32.3	43.3	34.6
Min Temperature (°C)	15.0	16.3	18.5	19.3	19.6	21.7	20.2	19.8	19.5	16.7	14.1	13.9	17.9
Wind Speed @ 2m	1.80	1.91	1.85	1.64	1.63	2.20	2.40	1.95	1.51	1.51	1.62	1.70	1.81
Average Relative Humidity (%)	54	53	54	55	49	46	57	60	57	49	48	52	53
Sunshine Duration (hrs)	9.0	9.3	8.8	8.6	9.3	8.7	7.4	7.4	7.7	8.8	9.7	9.6	8.7
PET (mm/day)	4.94	5.58	5.87	5.76	6.03	6.53	5.59	5.30	5.28	5.37	5.14	6.21	5.64
PET (mm/month)	153.14	156.24	181.97	172.80	186.93	195.90	173.29	164.30	158.40	166.47	154.20	192.51	2056.2

Melka Werer

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Maximum Temperature (°C)	31.3	32.7	34.5	35.5	37.3	37.9	35.2	33.5	34.9	34.3	32.5	31.2	34.2
Minimum Temperature (°C)	15.7	17.3	19.3	20.2	21.0	23.9	21.9	21.1	20.7	17.3	14.9	14.5	19.0
Wind Speed at 2m (km/hr)	4.5	4.7	5.1	4.9	5.5	8.0	8.1	6.9	5.5	4.7	4.5	4.3	5.5
Relative Humidity (%)	53	52	51	50	44	39	51	58	53	48	49	52	50
Sunshine Duration (hrs)	8.7	8.6	8.3	8.4	9.1	8.7	7.2	7.3	7.9	9.1	9.6	9.1	8.5
PET (mm/day)	4.43	4.92	5.45	5.62	6.10	6.95	6.02	5.46	5.51	5.26	4.74	4.30	5.40
PET (mm/month)	137.33	137.76	168.95	168.60	189.10	208.50	186.62	169.26	165.30	163.06	142.20	133.30	1970.0

Gewane

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Max Temperature (°C)	32.2	33.2	35.0	36.2	38.1	39.6	37.4	35.3	36.3	35.1	34.1	32.7	35.4
Min Temperature (°C)	16.3	17.7	18.8	19.6	20.5	22.7	21.3	20.6	21.8	18.2	15.6	15.1	19.0
Sunshine Duration (hrs)	8.9	8.6	8.4	8.8	10.0	8.6	7.5	8.1	9.0	9.7	9.9	9.6	8.9
Average Relative Humidity (%)	61	62	61	60	53	47	55	64	59	57	55	60	58
Wind Speed (m/s)	1.3	1.5	1.6	1.6	1.7	2.4	2.9	2.6	1.8	1.5	1.5	1.3	1.8
PET (mm/day)	4.46	4.98	5.52	5.88	6.47	7.18	6.86	6.18	6.05	5.54	5.10	4.49	5.73
PET (mm/month)	138.26	139.44	171.12	176.40	200.57	215.40	212.66	191.58	181.50	171.74	153.00	139.19	2090.9

Dubti

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Max Temperature (°C)	32.3	33.3	36.1	37.8	41.0	43.4	40.7	39.0	39.6	37.1	34.3	32.7	37.3
Min Temperature (°C)	18.0	19.5	21.7	22.7	24.7	25.9	25.8	25.3	24.8	20.9	18.0	17.1	22.0
Sunshine Duration (hrs)	8.8	7.9	8.2	9.4	9.8	8.7	7.0	7.9	8.0	8.8	10.0	9.7	8.7
Average Relative Humidity (%)	61	61	57	55	47	41	48	52	51	55	56	61	54
Wind Speed (m/s)	2.0	2.1	2.3	2.1	1.5	1.5	1.7	1.6	1.1	1.2	1.6	1.8	1.7
PET (mm/day)	4.92	5.28	6.28	6.80	6.74	6.73	6.26	5.97	5.62	5.29	5.18	4.83	5.83
PET (mm/month)	152.52	147.84	194.68	204.00	208.94	201.90	194.06	185.07	168.60	163.99	155.40	149.73	2126.7

Assaita

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Max Temperature (°C)	33.0	34.0	35.8	38.1	40.3	41.7	41.0	39.6	39.5	37.6	35.2	33.1	37.4
Min Temperature (°C)	17.9	18.4	20.0	21.8	23.1	24.3	24.2	23.0	22.9	20.7	18.7	17.6	21.0
Wind Speed @ 2m (m/s)	1.58	1.61	1.63	1.73	1.46	1.55	1.56	1.51	1.29	1.50	1.69	1.61	1.56
Average Relative Humidity (%)	80	76	71	70	67	64	68	72	69	71	73	77	72
Sunshine Duration (hrs)	8.8	9.6	9.2	9.5	10.1	8.2	7.9	8.3	8.3	9.5	10.0	9.4	9.1
PET (mm/day)	4.36	5.06	5.63	6.23	6.44	6.17	5.97	5.87	5.68	5.59	5.10	4.42	5.54
PET (mm/month)	135.16	141.68	174.53	186.90	199.64	185.10	185.07	181.97	170.40	173.29	153.00	137.02	2023.8

Annex 2b Potential Evapotranspiration (PET) for Selected Stations

Highlands (plateau and escarpment)

Shola Gebeya

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Max Temperature (°C)	19.1	20.4	20.9	20.6	22.0	21.4	18.1	17.6	18.7	18.9	18.9	18.8	19.6
Min Temperature (°C)	7.7	8.9	10.5	10.9	11.3	10.6	10.1	10.2	10.1	8.6	7.2	7.3	9.4
Relative Humidity Average	60	51	56	59	53	61	77	81	73	64	58	58	63
Wind Speed @ 2m (m/s)	2.0	2.2	2.5	2.5	2.8	2.2	1.9	1.8	1.7	2.2	2.0	2.0	2.1
Sunshine Duration (hrs)	8.1	8.2	7.6	7.1	8.3	6.5	4.2	4.2	6.1	8.1	9.4	8.8	7.2
PET (mm/day)	3.52	4.15	4.35	4.24	4.76	3.94	2.89	2.82	3.35	3.78	3.74	3.51	3.75
PET (mm/month)	109.12	116.20	134.85	127.20	147.56	118.20	89.59	87.42	100.50	117.18	112.20	108.81	1368.8

Majete

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Max Temperature (°C)	25	27	28	29	32	33	30	28	28	28	27	26	28
Min Temperature (°C)	12.1	13.0	14.8	16.0	16.4	17.6	16.8	16.2	15.2	13.2	11.2	11.1	14.5
Relative Humidity Average	64	57	57	56	48	39	61	70	68	61	55	58	58
Sunshine Duration (hrs)	6.5	6.3	6.5	6.8	9.0	6.7	5.6	6.3	6.3	8.1	8.6	8.5	7.1
Wind Speed (m/s)	1.1	1.3	1.3	1.2	1.3	1.4	1.2	1.0	0.9	0.9	1.1	1.1	1.1
PET (mm/day)	3.28	3.85	4.23	4.46	5.18	4.98	4.13	3.99	3.92	4.02	3.84	3.56	4.12
PET (mm/month)	101.68	107.80	131.13	133.80	160.58	149.40	128.03	123.69	117.60	124.62	115.20	110.36	1503.9

Kombolcha (Wello)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Max Temperature (°C)	24.2	25.3	26.3	27.0	28.3	30.1	27.9	26.5	25.9	25.1	24.6	24.1	26.3
Min Temperature (°C)	10.0	10.9	12.4	13.2	13.6	14.5	14.1	13.8	12.9	10.3	8.3	8.6	11.9
Relative Humidity Average (%)	62	60	60	59	49	40	58	64	64	60	57	60	58
Sunshine Duration (°C)	7.6	7.5	7.0	7.2	8.1	6.5	5.3	5.9	6.0	7.9	8.6	8.1	7.1
Wind Speed (m/s)	1.3	1.4	1.3	1.3	1.3	1.5	1.5	1.3	1.1	0.8	0.9	1.1	1.2
PET (mm/day)	3.47	3.91	4.14	4.37	4.70	4.79	4.14	3.97	3.79	3.68	3.47	3.31	3.98
PET (mm/month)	107.57	109.48	128.34	131.10	145.70	143.70	128.34	123.07	113.70	114.08	104.10	102.61	1451.8

Bati

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Max Temperature (°C)	24.7	25.6	27.1	29.0	31.1	32.8	30.8	28.9	29.1	28.2	26.8	25.2	28.3
Min Temperature (°C)	11.2	11.8	13.6	14.7	15.2	17.0	16.1	15.4	14.2	11.5	10.4	10.4	13.4
Relative Humidity Average	71	67	67	62	53	44	58	67	64	59	59	63	61
Wind Speed @ 2m (m/s)	0.9	1.0	1.0	1.0	1.0	1.2	1.3	1.1	0.8	0.7	0.8	0.9	1.0
Sunshine Duration (hrs)	7.3	6.6	7.4	7.9	9.0	8.5	7.0	7.4	7.4	8.4	9.4	8.5	7.9
PET (mm/day)	3.19	3.55	4.10	4.48	4.85	5.07	4.58	4.34	4.14	3.91	3.68	3.31	4.10
PET (mm/month)	98.89	99.40	127.10	134.40	150.35	152.10	141.98	134.54	124.20	121.21	110.40	102.61	1497.2

Tinsae Birhan (Abomsa)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Max Temperature (°C)	26.4	28.0	28.5	28.8	29.8	30.8	28.3	28.1	28.0	27.8	27.4	26.5	28.2
Min Temperature (°C)	13.7	14.5	15.8	16.9	17.3	17.3	16.1	16.0	15.9	15.0	13.6	13.2	15.4
Relative Humidity Average (%)	61	54	55	55	50	51	63	68	67	60	52	55	58
Wind Speed @ 2m (m/s)	1.8	2.1	2.1	2.1	2.2	2.3	2.2	1.7	1.2	1.4	1.7	1.8	1.9
Sunshine Duration (hrs)	8.1	8.3	7.9	7.1	8.7	8.4	6.9	7.1	6.8	7.5	9.1	9.1	7.9
PET (mm/day)	4.17	4.94	5.14	5.09	5.58	4.28	4.68	4.45	4.18	4.32	4.55	4.32	4.64
PET (mm/month)	129.27	138.32	159.34	152.70	172.98	128.40	145.08	137.95	125.40	133.92	136.50	133.92	1693.8

Annex 3 Stream Flow Data for Selected Stations

Stations		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Awash at Wonji (1969-2003)	Mean Flow (m^3/s)	33.018	33.069	32.108	32.659	34.827	37.282	42.465	61.780	56.911	42.284	36.594	35.852	39.904
	Mean Flow (MCM)	88.4	80.0	86.0	84.7	93.3	96.6	113.7	165.5	147.5	113.3	94.9	96.0	105.0
	CV	0.34	0.36	0.32	0.41	0.43	0.32	0.40	0.63	0.44	0.28	0.41	0.41	0.40
	No of Years	33	34	33	35	33	31	30	27	23	30	32	32	31
Awash at Nura Hera (1975-1995)	Mean Flow (m^3/s)	35.843	35.780	35.391	36.405	38.050	37.972	54.384	73.543	97.032	45.425	34.713	35.460	46.667
	Mean Flow (MCM)	96.0	86.6	94.8	94.4	101.9	98.4	145.7	197.0	251.5	121.7	90.0	95.0	122.7
	CV	0.27	0.24	0.25	0.20	0.39	0.31	0.32	0.28	0.50	0.24	0.36	0.33	0.31
	No of Years	19	18	19	19	19	20	20	19	19	18	19	19	19
Awash at Metahara (1982-2003)	Mean Flow (m^3/s)	21.637	21.969	21.633	21.412	24.834	22.625	39.675	80.992	88.840	33.197	20.578	21.602	34.916
	Mean Flow (MCM)	58.0	53.1	57.9	55.5	66.5	58.6	106.3	216.9	230.3	88.9	53.3	57.9	91.9
	CV	0.49	0.52	0.43	0.28	0.54	0.48	0.43	0.65	0.68	0.58	0.48	0.49	0.50
	No of Years	22	22	22	22	22	21	20	20	19	22	22	22	21
Awash at Awash (1969-2003)	Mean Flow (m^3/s)	33.517	34.761	40.005	40.785	40.209	36.202	72.383	130.046	136.400	49.545	32.308	30.742	56.409
	Mean Flow (MCM)	89.8	84.1	107.1	105.7	107.7	93.8	193.9	348.3	353.5	132.7	83.7	82.3	148.6
	CV	0.44	0.50	0.51	0.47	0.57	0.47	0.47	0.46	0.53	0.58	0.64	0.44	0.51
	No of Years	35	35	34	35	35	33	33	33	33	34	35	35	34
Awash at Melka Sadi (1983-2003)	Mean Flow (m^3/s)	29.333	28.472	31.671	37.500	34.060	30.482	62.929	121.081	116.198	53.760	28.727	25.428	49.970
	Mean Flow (MCM)	78.6	68.9	84.8	97.2	91.2	79.0	168.5	324.3	301.2	144.0	74.5	68.1	131.7
	CV	0.41	0.48	0.43	0.52	0.52	0.50	0.44	0.40	0.45	0.68	0.57	0.32	0.48
	No of Years	19	20	20	20	18	19	19	19	18	19	19	19	19
Awash at Melka Werer (1973-2003)	Mean Flow (m^3/s)	29.936	32.719	38.386	40.621	34.117	27.109	78.595	161.021	127.479	51.739	31.211	27.943	56.740
	Mean Flow (MCM)	80.2	79.2	102.8	105.3	91.4	70.3	210.5	431.3	330.4	138.6	80.9	74.8	149.6
	CV	0.34	0.54	0.43	0.51	0.53	0.40	0.39	0.27	0.42	0.61	0.72	0.39	0.46
	No of Years	26	27	28	30	29	28	30	30	29	27	30	31	29
Awash at Adaitu (1979-2003)	Mean Flow (m^3/s)	25.429	24.977	34.668	42.950	32.769	22.892	41.145	113.767	119.348	92.774	54.356	34.642	53.310
	Mean Flow (MCM)	68.1	60.4	92.9	111.3	87.8	59.3	110.2	304.7	309.4	248.5	140.9	92.8	140.5
	CV	0.53	0.47	0.61	0.43	0.55	0.58	0.59	0.61	0.71	0.53	0.52	0.61	0.56
	No of Years	23	22	22	21	22	20	20	20	23	21	22	22	22
Awash at Tendaho (1969-2003)	Mean Flow (m^3/s)	33.302	41.567	66.374	72.771	44.995	28.990	67.549	168.314	123.712	85.034	59.522	38.863	69.250
	Mean Flow (MCM)	89.2	100.6	177.8	188.6	120.5	75.1	180.9	450.8	320.7	227.8	154.3	104.1	182.5
	CV	0.65	0.89	0.98	0.72	0.54	0.70	0.71	0.68	0.64	0.60	0.68	0.46	0.69
	No of Years	30	33	33	32	30	31	32	32	32	33	28	29	31
Keleta nr Sire (1967-2003)	Mean Flow (m^3/s)	1.183	1.633	2.314	2.858	3.027	2.784	8.074	16.332	13.407	5.110	1.713	1.221	4.971
	Mean Flow (MCM)	3.2	3.9	6.2	7.4	8.1	7.2	21.6	43.7	34.8	13.7	4.4	3.3	13.1
	CV	0.71	1.21	1.09	1.08	0.87	0.67	0.45	0.40	0.65	0.85	0.79	0.71	0.79
	No of Years	36	36	35	35	34	35	34	36	35	35	36	37	35
Kesem at Awara Melka (1969-2003)	Mean Flow (m^3/s)	2.161	2.875	3.542	3.160	2.891	4.021	34.055	77.430	29.856	7.355	3.230	2.447	14.419
	Mean Flow (MCM)	5.8	7.0	9.5	8.2	7.7	10.4	91.2	207.4	77.4	19.7	8.4	6.6	38.3
	CV	0.72	1.07	1.18	0.88	1.13	1.20	0.73	0.43	0.95	0.84	0.92	0.98	0.92
	No of Years	33	33	34	34	34	33	32	34	32	33	33	33	33
Mille at Mille (1981-2003)	Mean Flow (m^3/s)	2.214	4.116	9.876	9.017	4.642	1.046	16.639	36.175	11.010	4.545	2.579	2.884	8.729
	Mean Flow (MCM)	5.9	10.0	26.5	23.4	12.4	2.7	44.6	96.9	28.5	12.2	6.7	7.7	23.1
	CV	1.01	2.19	1.06	0.64	1.01	0.87	1.25	0.99	0.79	1.27	1.30	0.99	1.11
	No of Years	21	20	20	20	18	20	20	21	20	18	19	19	20

MCM: Million Cubic Meters; CV: Coefficient of Variation; nr: near

Annex 4 Amibara Groundwater Data (Selected Piezometers)

Piezometer	UTME	UTMN	Record Period (Year)	GW Depth July 03 - June 04 (m) *	GW Elevation July 03 - June 04 (m) *	GW Salinity July 03 - June 04 (EC, mS/cm) *
AIP 2	622647	1021688	16	1.90		
AIP 3	624013	1023461	20	2.16		
AIP 3/1	624017	1023468	18	3.19	740.41	13.04
AIP 3/2	624021	1023472	17	3.99		
AIP 6	625416	1022335	18	2.30	742.10	5.62
AIP 7	622533	1025399	19	3.32	737.65	17.98
AIP 9	622158	1026950	9			4.53
AIP 10	625723	1024871	16	2.99		7.65
AIP 10/1	625720	1024866	14	4.31	736.92	
AIP 10/2	625714	1024862	14	3.16		
AIP 10/3	625708	1024855	14	1.80		
AIP 11	623114	1028338	19	4.18	735.71	10.13
AIP 12	624241	1026951	19	4.19	734.45	5.17
AIP 14	627274	1024361	16	2.31	740.01	7.88
AIP 14/3	627283	1024347	13	1.66		
AIP 18	628133	1025888	18	3.78	737.70	11.31
AIP 19	626894	1027990	20	4.07	734.87	9.58
AIP 20	628553	1028273	12	3.00	735.75	13.06
AIP 21	630322	1028876	18	3.39	733.92	6.18
AIP 22	629117	1029240	19	3.40	734.32	
AIP 23	626354	1025754	16	2.58	738.00	4.58
AIP 27	623460	1021443	18	3.15		2.66
AIP 27/1	623466	1021450	17	3.15		
AIP 27/2	623462	1021447	17	3.40	742.69	
AIP 27/3	623455	1021447	17	1.78		
AIP 28	621809	1022997	17	1.97	742.61	2.04
AIP 30	620880	1027180	17	1.47	738.53	
AIP 32	628602	1032893	19	4.83	730.70	1.73
AIP 34	631089	1031479	15	2.76		
AIP 35	630922	1032954	19	2.55	731.57	8.00
AIP 37	632057	1033895	19	3.11	730.41	3.40
AIP 39	627746	1038000	19	6.00	727.44	
AIP 40 A	630040	1038005	18	3.02	729.64	2.05
AIP 41	630711	1036251	20	1.96	730.60	8.68
AIP 42	632693	1036644	20	2.24	729.40	29.45
AIP 43	632109	1038139	18	2.27	729.16	8.96
AIP 44	630698	1039192	19	2.86	729.23	11.08
AIP 45	629558	1040513	15	3.26	727.00	3.90
AIP 46	632092	1039914	20	3.90	727.43	17.89
AIP 47	634240	1038898	19	2.60	727.55	9.60
AIP 49	631010	1043143	13	3.13	726.00	19.50
AIP 50	632996	1041779	20	3.17	725.57	14.18
AIP 51	635023	1041206	16	2.86	727.00	
AIP 52	635975	1040028	18	5.61	724.53	10.34
AIP 53	633973	1043289	6	3.00		
AIP 54	636998	1041713	18	6.40	721.90	5.65
AIP 55	633899	1045397	20	3.14	723.85	2.59
AIP 60	627084	1036343	15	6.64	728.38	2.11
AIP 62	631444	1045102	17	6.63	721.51	17.67
AIP 63	629462	1035127	15	4.40	730.12	6.14
AIP 64	631692	1035507	17	2.10	730.86	
AIP 65	630504	1037889	17	2.13	731.13	1.23
PP 1	628833	1029710	15	5.11	733.16	1.70
P 2	627924	1034244	19	9.28	726.27	2.49
PP 9	632300	1044901	19	6.71	721.56	3.84
P 11	624973	1024211	19	1.87	740.09	6.00

* Average values (July 2003 - June 2004) used to prepared Maps (Figures 5.4, 5.5 & 6.4); some data estimated

Annex 5a Amibara Soil Database (This Study)

Lab No.	Field Code	UTM Easting	UTM Northing	Sampling Date	Depth (cm)	pHe	ECe (mS/cm)	Na (meq/l)	Ca (meq/l)	Mg (meq/l)	SARe	Textural Class
1	C6/4	628915	1037505	4-May-04	0-30	8.56	0.82	3.58	2.27	1.87	2.49	silty clay loam
2	F10/2/9#2	634350	1039896	29-Apr-04	0-30	8.51	0.81	3.59	3.07	1.13	2.48	clay
3	F3/3/34	625573	1025902	22-Apr-04	30-60	8.62	0.85	4.07	3.13	0.73	2.93	silty clay
4	F10/9/2 #1	634289	1042718	27-Apr-04	0-30	8.64	0.56	3.11	1.80	0.93	2.66	silt loam
5	AB/5	630050	1031553	7-May-04	0-30	8.57	0.73	4.00	2.20	1.27	3.04	clay
6	F10/4/2	632536	1040608	26-Apr-04	0-30	8.54	0.82	4.28	2.00	2.13	2.98	silt loam
7	F4/3/22A	629711	1028942	23-Apr-04	0-30	8.64	0.57	3.70	1.47	0.40	3.83	silty clay
8	B7/6	627358	1038267	4-May-04	0-30	8.22	3.86	13.11	17.41	8.40	3.65	loam
9	F9/2/2	630620	1037190	30-Apr-04	0-30	8.62	0.68	3.73	1.53	1.33	3.11	silty clay loam
10	F5A/1	630685	1030601	28-Apr-04	0-30	8.67	0.63	3.85	2.73	0.40	3.08	silty clay
11	AM3/7	632566	1043919	6-May-04	0-30	8.77	0.67	4.69	1.13	1.47	4.11	silty clay loam
12	B7/5	627742	1038490	4-May-04	0-30	8.28	3.63	8.14	23.75	3.47	2.21	silt loam
13	B7/Z3	628148	1039364	4-May-04	0-30	8.36	2.01	7.18	9.94	2.60	2.87	silt loam
14	MMP/7	629363	1037095	4-May-04	0-30	8.55	0.54	2.90	1.13	1.07	2.76	loam
15	AL 2/10	629247	1039686	5-May-04	0-30	8.57	0.71	3.45	3.20	1.20	2.33	silty clay loam
16	F6/28B#2	634678	1037672	29-Apr-04	0-30	8.65	0.80	4.97	2.60	0.93	3.74	clay
17	AL 6/P	628418	1041569	5-May-04	0-30	8.50	1.05	4.97	3.94	1.07	3.14	silt loam
18	AL 5/1	629548	1040188	5-May-04	90-120	8.54	0.54	3.86	0.80	0.80	4.32	silty clay loam
19	F3/2/31	627866	1026266	22-Apr-04	0-30	8.50	0.65	4.67	2.33	0.27	4.10	silty clay loam
20	AM/ZW/1	633352	1044677	6-May-04	0-30	8.54	0.77	3.80	3.54	0.80	2.58	silty clay loam
21	AL 4/3	628753	1040480	5-May-04	0-30	8.23	1.97	5.18	9.07	2.93	2.11	clay loam
22	MMP/3A/P	629603	1035701	4-May-04	0-30	8.41	4.85	8.00	37.09	5.54	1.73	silt loam
23	AM/KM/1	633650	1044139	6-May-04	0-30	8.49	1.47	8.41	3.54	1.60	5.25	silty clay loam
24	F3/4/46	625577	1026266	22-Apr-04	0-30	8.35	0.77	3.04	2.33	2.33	1.99	silty clay
25	AL 4/7	629184	1040495	5-May-04	0-30	8.41	0.54	2.14	2.80	0.33	1.71	silty clay loam
26	F9/3/17A	632002	1038044	30-Apr-04	0-30	8.50	0.65	3.31	2.33	1.00	2.56	silty clay loam
27	AL 8/8	630388	1040433	5-May-04	0-30	8.47	1.83	8.41	6.94	2.87	3.80	silt loam
28	F9/1/7	631837	1037087	30-Apr-04	0-30	8.56	0.88	3.93	3.54	0.93	2.63	silty clay
29	F3/2/26	627219	1025322	22-Apr-04	0-30	7.94	0.53	2.66	1.93	0.60	2.36	clay
30	AN/BA/4	635243	1045150	6-May-04	0-30	7.82	0.61	4.68	0.80	0.47	5.87	silty clay
31	AL 6/4	628487	1041137	5-May-04	0-30	8.00	0.96	4.44	4.60	0.20	2.87	silty clay loam
32	F10/8/5	635067	1042260	27-Apr-04	0-30	7.85	22.19	7.87	7.40	6.00	3.04	silty clay
33	C5/4	629144	1035950	4-May-04	0-30	8.15	0.84	3.12	4.40	0.60	1.97	silt loam
34	AL 9/3	630878	1040226	5-May-04	0-30	8.14	1.77	6.24	7.00	3.40	2.74	silt loam
35	AL 2/2	628514	1040052	5-May-04	0-30	8.14	0.97	4.08	4.00	1.80	2.40	silt loam
36	ER/108	628524	1032183	10-May-04	0-30	8.22	0.82	4.56	2.80	1.20	3.22	silty clay
37	ER/Forest # 1	627122	1032948	10-May-04	0-30	8.50	0.73	2.64	3.80	1.20	1.67	silt loam
38	ER/CPD#2	629673	1032115	11-May-04	0-30	8.35	0.60	3.84	1.80	0.20	3.84	silt loam
39	ER/123	627543	1033116	10-May-04	0-30	8.30	1.40	6.84	6.20	1.80	3.42	silt loam
40	ER/Forest # 2	628862	1032988	10-May-04	0-30	8.29	0.68	3.60	3.00	0.80	2.61	loam
41	ER 210	628725	1032589	10-May-04	0-30	8.28	0.84	4.80	2.80	1.20	3.39	silty clay loam
42	F3/4/56	626533	1028440	22-Apr-04	0-30	8.03	0.56	3.48	1.80	1.00	2.94	clay
43	MMP/5A	629673	1036564	4-May-04	0-30	8.40	0.70	3.96	2.20	1.00	3.13	silty clay loam
44	F6/23A	632957	1036848	24-Apr-04	0-30	8.44	0.94	4.80	4.20	0.80	3.04	clay
45	F11/6/6	634811	1040210	27-Apr-04	0-30	8.52	0.63	3.84	1.80	0.80	3.37	clay
46	F6/21	632484	1036631	24-Apr-04	0-30	8.39	0.73	3.84	3.00	0.80	2.79	clay
47	AB/2	629228	1033643	7-May-04	0-30	8.16	1.61	5.76	7.60	3.40	2.46	clay loam
48	F6/14A	632005	1035060	24-Apr-04	0-30	8.31	1.26	5.52	4.80	2.20	2.95	silty clay
49	F11/3/3	633158	1038292	24-Apr-04	0-30	8.42	0.56	3.24	2.00	0.60	2.84	clay
50	F1/2B/73	625419	1028270	21-Apr-04	0-30	8.15	2.54	9.60	10.20	5.00	3.48	clay

Sampled by: Gedion Tsegaye Sahle (AAU, School of Graduate Studies, MSc. Hydrogeology Stream); Laboratory Analyses: in May-June 2004, by Gedion Tsegaye & EARO - Werer Research Center Staff

Annex 5b Amibara Soil Database (This Study)

Lab No.	Field Code	UTM Easting	UTM Northing	Sampling Date	Depth (cm)	pHe	ECe (mS/cm)	Na (meq/l)	Ca (meq/l)	Mg (meq/l)	SARe	Textural Class
51	F4/2/14B	627814	1028093	23-Apr-04	0-30	8.41	0.73	4.20	2.20	1.00	3.32	silty clay loam
52	AM/KE	631486	1041900	6-May-04	0-30	8.33	0.91	4.68	3.60	1.40	2.96	silty clay
53	AM/BA/3	634458	1044980	6-May-04	0-30	8.81	0.95	5.16	2.40	1.80	3.56	silty clay
54	F3/2/23	626840	1024797	22-Apr-04	0-30	8.33	2.91	7.32	12.53	8.47	2.26	silty clay loam
55	F11/2/3	632407	1038444	24-Apr-04	0-30	8.08	0.67	3.24	2.27	1.73	2.29	silty clay
56	F6/7A	630602	1033797	1-May-04	0-30	8.45	0.64	3.72	2.27	0.93	2.94	silty clay loam
57	AL 11/10	630692	1041124	5-May-04	0-30	8.43	0.85	3.84	3.73	1.07	2.48	silty clay
58	F10/2/15	635104	1041217	27-Apr-04	0-30	8.20	0.82	4.68	3.20	1.10	3.19	clay
59	C4/6	629020	1035038	4-May-04	0-30	8.21	0.94	2.76	5.20	2.70	1.39	silty clay loam
60	ER/113	628146	1032536	10-May-04	0-30	8.35	0.81	5.16	2.40	1.20	3.85	silt loam
61	AM 3/4/P	631523	1043397	6-May-04	0-30	8.23	0.91	5.16	3.30	1.40	3.37	silty clay
62	D2/22	631458	1035474	1-May-04	0-30	8.65	1.13	5.88	3.50	1.60	3.68	clay
63	F9/1/5	631433	1037088	30-Apr-04	0-30	8.58	0.78	3.84	1.80	2.30	2.68	clay
64	F5A/2B	630973	1030364	28-Apr-04	0-30	8.15	0.96	5.64	2.60	1.30	4.04	clay
65	D3/1/3	630025	1036392	1-May-04	0-30	8.57	0.74	3.48	2.10	1.60	2.56	clay loam
66	AM/MO/2	633122	1043254	7-May-04	0-30	8.60	0.89	4.08	4.10	1.40	2.46	clay loam
67	F4/1/1A	628580	1026029	23-Apr-04	0-30	8.34	0.63	3.24	2.30	1.30	2.41	clay
68	AN/KM/3	635082	1044732	6-May-04	0-30	8.42	0.96	4.68	4.80	1.10	2.72	clay
69	F10/2/1	631730	1039743	26-Apr-04	0-30	8.48	0.77	3.96	2.70	1.20	2.84	silty clay loam
70	D2/6	630245	1035602	1-May-04	0-30	8.23	2.65	8.40	11.80	6.10	2.81	silty clay loam
71	1A3/2	627924	1036577	3-May-04	0-30	8.22	0.79	2.88	4.30	0.50	1.86	clay loam
72	AL 1/5	627750	1040302	5-May-04	0-30	8.29	1.33	4.68	7.50	0.70	2.31	silty clay loam
73	D3/3/3	630791	1036890	30-Apr-04	0-30	8.21	13.40	44.58	67.40	22.60	6.65	silt loam
74	AM/AS	630988	1042675	6-May-04	0-30	8.56	0.94	3.60	4.60	0.90	2.17	silt loam
75	AM/3/1/P	631782	1042892	6-May-04	0-30	8.40	0.95	4.08	3.90	2.00	2.38	silty clay loam
76	D3/2/3	630452	1036254	1-May-04	0-30	7.93	28.19	101.08	152.70	27.90	10.64	silt loam
77	MMP/1B	629054	1034235	4-May-04	0-30	8.28	0.73	3.00	2.70	2.20	1.92	clay
78	AL 8/3	629834	1040501	5-May-04	0-30	8.67	0.89	4.72	3.10	1.20	3.22	silty clay
79	AM/MO/1	633298	1045049	7-May-04	0-30	8.26	0.66	3.12	2.40	1.00	2.39	silty clay loam
80	F4/1/4	629095	1027240	23-Apr-04	0-30	8.61	0.80	3.48	2.10	1.60	2.56	silty clay
81	AL 10/6	629423	1041595	5-May-04	0-30	8.70	0.95	4.32	3.40	1.90	2.65	silty clay
82	AB/7	630441	1029929	7-May-04	0-30	8.37	0.61	2.64	1.20	2.80	1.87	silty clay loam
83	ER/104	628857	1032022	10-May-04	0-30	8.54	1.57	4.80	9.70	1.70	2.01	silt loam
84	F6/27A	633819	1037138	29-Apr-04	0-30	8.82	0.72	3.96	2.50	0.80	3.08	clay
85	ER/118	627824	1032849	10-May-04	0-30	8.66	0.77	2.76	3.90	1.40	1.70	silty clay loam
86	F6/20A	632138	1036336	24-Apr-04	0-30	8.75	0.99	4.80	2.60	1.10	3.53	clay
87	ER/220	628094	1033182	10-May-04	0-30	8.75	0.68	3.48	1.70	2.10	2.52	silty clay
88	ER/001	629454	1032163	10-May-04	0-30	8.75	0.68	3.60	2.00	1.10	2.89	silty clay loam
89	F4/2/14C	628084	1028210	23-Apr-04	0-30	8.33	6.50	27.86	39.00	1.60	6.18	silty clay
90	D3/1/1	629920	1036644	1-May-04	0-30	8.93	0.78	4.44	2.40	1.30	3.26	silt loam
91	F4/1/6A	629568	1027887	23-Apr-04	0-30	8.71	1.15	5.16	4.10	1.20	3.17	silty clay
92	D2/8	630452	1035759	1-May-04	0-30	8.48	2.76	6.59	15.00	5.00	2.08	silty clay
93	D3/3/4	630918	1037084	30-Apr-04	0-30	8.01	31.65	97.12	179.70	35.50	9.36	silt loam
94	D3/3/2	630638	1037025	30-Apr-04	0-30	8.47	7.00	27.47	32.40	10.00	5.97	loam
95	30 H/A	628501	1034334	4-May-04	0-30	8.73	1.27	4.80	6.30	1.60	2.42	silt loam
96	F4/3/20A	628850	1028655	23-Apr-04	0-30	8.66	0.96	5.04	4.10	0.90	3.19	silty clay
97	ER/102	629054	1031956	10-May-04	0-30	8.92	1.15	5.76	4.30	2.00	3.25	silt loam
98	AM/GZ/1	634080	1045647	7-May-04	0-30	8.61	2.76	8.16	12.30	5.70	2.72	silt loam
99	D2/9	629965	1034955	1-May-04	0-30	8.82	0.87	5.88	1.70	1.90	4.38	silty clay loam
100	AM/BA/2	633968	1044460	6-May-04	0-30	8.11	24.10	85.22	116.20	36.00	9.77	silty clay loam

Sampled by: Gedion Tsegaye Sahle (AAU, School of Graduate Studies, MSc. Hydrogeology Stream); Laboratory Analyses: in May-June 2004, by Gedion Tsegaye & EARO - Werer Research Center Staff

Annex 5c Amibara Soil Database (This Study)

Lab No.	Field Code	UTM Easting	UTM Northing	Sampling Date	Depth (cm)	pHe	ECe (mS/cm)	Na (meq/l)	Ca (meq/l)	Mg (meq/l)	SARe	Textural Class
101	F3/1/2	626093	1022555	21-Apr-04	0-30	8.30	2.08	16.86	1.60	0.80	15.39	loam
102	F3/1/5	626517	1023237	21-Apr-04	0-30	8.50	2.87	23.32	3.60	2.00	13.94	silt loam
103	1C11	623665	1022680	19-Apr-04	0-30	8.31	4.15	17.98	17.60	6.40	5.19	silt loam
104	2D28	623122	1024201	20-Apr-04	0-30	8.42	1.09	8.99	1.20	0.80	8.99	silty clay
105	F1/3/42	623230	1028590	20-Apr-04	0-30	8.49	1.06	6.46	3.20	1.60	4.17	silt loam
106	4A1	625179	1022340	19-Apr-04	0-30	8.53	0.71	5.62	2.00	0.40	5.13	silt loam
107	2C11	624102	1025207	20-Apr-04	0-30	8.51	0.94	8.15	1.20	0.40	9.11	silty clay loam
108	3A10	624668	1023772	19-Apr-04	0-30	8.31	0.93	6.18	3.20	0.40	4.61	silt loam
109	F4/1/2A	628765	1026470	23-Apr-04	0-30	8.45	0.75	7.31	0.40	0.40	11.55	loam
110	F1/2C/23	620933	1025399	20-Apr-04	0-30	7.67	78.20	271.54	359.60	148.40	17.04	silty clay
111	F1/3/26	620705	1026139	20-Apr-04	0-30	8.51	1.41	8.99	4.80	1.20	5.19	silty clay loam
112	2A3	624467	1023310	19-Apr-04	0-30	8.12	48.00	354.27	87.60	32.00	45.81	silt loam
113	F1/3/31	620929	1027485	20-Apr-04	0-30	8.42	1.80	9.84	7.20	0.80	4.92	silt loam
114	4C2	625716	1023387	20-Apr-04	0-30	8.07	23.40	127.07	81.60	21.20	17.72	silt loam
115	F3/1/18	628400	1025723	21-Apr-04	30-60	8.27	2.01	17.98	3.60	0.40	12.72	silt loam
116	F3/3/37	625836	1026403	22-Apr-04	0-30	8.32	0.86	6.18	1.60	0.80	5.64	clay
117	F1/1/7	621578	1023319	20-Apr-04	0-30	8.57	0.91	5.62	2.00	1.60	4.19	silty clay loam
118	1V2	623459	1021412	19-Apr-04	0-30	8.54	0.58	3.93	0.80	0.40	5.08	silty clay loam
119	1C1#1	623108	1020975	19-Apr-04	0-30	8.67	0.81	5.62	2.00	1.20	4.44	silty clay loam
120	1V4	624248	1021659	19-Apr-04	0-30	8.65	1.62	9.27	4.80	3.20	4.64	silty clay loam
121	1C6	623422	1022117	19-Apr-04	0-30	8.68	0.81	5.34	2.00	1.60	3.98	silt loam
122	2D18	623516	1023953	20-Apr-04	0-30	8.67	0.70	4.50	2.00	1.20	3.55	silty clay loam
123	1V2#2	623420	1021662	19-Apr-04	0-30	8.50	3.44	19.11	11.20	4.40	6.84	clay loam
124	1B3	622828	1022137	19-Apr-04	0-30	8.60	0.78	5.90	1.60	0.40	5.90	silty clay loam
125	F1/1/11	621325	1024221	20-Apr-04	0-30	7.89	48.80	146.32	238.00	100.80	11.24	silt
126	1B9	623010	1021968	19-Apr-04	0-30	8.31	10.35	77.22	19.20	12.40	19.43	silt
127	3B16	624336	1026196	20-Apr-04	0-30	8.50	0.61	5.06	0.80	0.40	6.53	silt loam
128	F1/2B/53	623253	1027138	21-Apr-04	0-30	8.65	0.67	3.93	2.00	1.20	3.11	clay
129	PK1	625529	1022101	22-Apr-04	0-30	10.31	49.00	477.54	3.60	2.80	266.95	silty clay loam
130	1C9	623898	1022547	19-Apr-04	0-30	8.47	12.30	81.61	21.60	18.40	18.25	silt loam
131	F4/3/16A	628317	1027032	23-Apr-04	0-30	8.33	3.32	12.08	18.00	4.80	3.58	clay
132	2B6	623020	1024113	19-Apr-04	0-30	8.75	1.15	6.46	4.80	1.20	3.73	clay
133	3A1	624205	1022260	19-Apr-04	0-30	8.43	6.00	22.76	32.00	5.60	5.25	silty clay loam
134	3B7	623600	1026096	20-Apr-04	0-30	8.48	3.38	12.36	16.00	7.60	3.60	clay
135	F10/7/2	633515	1041878	27-Apr-04	0-30	8.65	0.99	6.45	2.00	1.20	5.10	loam
136	F10/2/3	632091	1040042	26-Apr-04	0-30	8.84	0.87	5.34	2.40	1.20	3.98	silty clay loam
137	F10/10/2	634817	1042509	27-Apr-04	0-30	8.61	1.41	5.90	3.60	4.40	2.95	clay
138	AL 5/6	629978	1040006	5-May-04	0-30	8.74	0.91	5.06	2.80	1.60	3.41	loam
139	D3/1/2	629962	1036565	1-May-04	0-30	8.11	27.40	61.91	153.20	66.00	5.91	silt loam
140	B7/Z2	627533	1039675	4-May-04	0-30	8.69	0.54	2.53	2.00	0.80	2.14	silt loam
141	AM/GZ/3	630669	1043404	7-May-04	0-30	8.86	0.78	5.34	1.20	0.80	5.34	silty clay loam
142	F5B/11A	631189	1033646	28-Apr-04	0-30	8.23	10.66	39.78	59.20	9.60	6.78	silty clay loam
143	AL 5/1	629548	1040188	5-May-04	0-30	8.63	1.01	3.37	6.40	1.20	1.73	silty clay loam
144	1A1	622334	1021308	19-Apr-04	90-120	8.69	0.72	5.90	1.20	0.40	6.60	silt loam
145	3B2	624461	1024487	20-Apr-04	0-30	8.72	0.94	6.18	2.40	0.80	4.89	silty clay loam
146	1C5	623878	1022287	19-Apr-04	0-30	8.17	21.22	101.30	89.20	24.00	13.46	silt loam
147	F1/1/4	622425	1023053	20-Apr-04	0-30	7.88	49.60	174.46	248.80	74.80	13.72	silt loam
148	F11/8/3	637185	1041544	28-Apr-04	0-30	8.77	0.77	6.18	1.35	0.65	6.18	silty clay
149	1C9	623898	1022547	19-Apr-04	0-30	8.64	0.88	4.50	1.60	3.20	2.90	silt loam
150	F10/6/2	633049	1041246	26-Apr-04	0-30	8.60	0.92	6.74	3.60	0.40	4.77	silty clay loam

Sampled by: Gedion Tsegaye Sahle (AAU, School of Graduate Studies, MSc. Hydrogeology Stream); Laboratory Analyses: in May-June 2004, by Gedion Tsegaye & EARO - Werer Research Center Staff

Annex 5d Amibara Soil Database (This Study)

Lab No.	Field Code	UTM Easting	UTM Northing	Sampling Date	Depth (cm)	pHe	ECe (mS/cm)	Na (meq/l)	Ca (meq/l)	Mg (meq/l)	SARe	Textural Class
151	F6/17	631970	1035320	24-Apr-04	0-30	8.50	0.95	6.46	2.80	0.80	4.82	silty clay
152	F1/2B/61	623749	1027088	21-Apr-04	0-30	8.77	0.69	5.34	1.07	0.93	5.34	clay
153	F1/2B/70	624668	1027597	21-Apr-04	0-30	8.13	0.63	5.90	0.81	0.39	7.62	clay
154	F3/1/4	626363	1023051	21-Apr-04	0-30	8.82	0.81	7.31	1.20	0.40	8.17	clay loam
155	F3/1/17	628337	1025531	21-Apr-04	0-30	8.57	7.05	55.69	10.40	6.40	19.21	clay
156	F3/2/24	626185	1025321	22-Apr-04	0-30	8.39	3.58	14.89	18.00	3.60	4.53	silt loam
157	F10/2/8	633449	1040062	26-Apr-04	60-90	8.61	0.77	5.06	2.40	0.80	4.00	clay
158	3A3	624732	1022925	19-Apr-04	0-30	8.67	0.65	4.22	2.40	0.80	3.33	silty clay loam
159	F1/3/28	620568	1026546	20-Apr-04	0-30	8.60	1.52	8.15	5.20	1.60	4.42	silty clay loam
160	F3/1/11	627607	1024258	21-Apr-04	0-30	8.76	2.74	21.36	4.40	2.00	11.94	sandy clay loam
161	F3/1/16	628253	1025330	21-Apr-04	0-30	8.84	0.99	8.15	1.20	0.80	8.15	silty clay
162	F4/1/6B	629826	1028107	23-Apr-04	0-30	8.64	1.06	7.59	1.20	0.80	7.59	silt loam
163	4B4	625197	1024061	20-Apr-04	90-120	8.33	7.73	63.64	12.80	3.20	22.50	silty clay loam
164	F4/3/17	628425	1027865	23-Apr-04	0-30	8.57	0.79	5.62	1.60	0.40	5.62	silt loam
165	F3/2/29	627659	1025909	22-Apr-04	0-30	8.39	4.38	16.86	21.20	6.40	4.54	silt loam
166	F3/3/38	626650	1026192	22-Apr-04	0-30	8.73	0.72	4.22	1.89	1.31	3.33	silty clay
167	F1/2B/46	622092	1026048	21-Apr-04	0-30	8.65	1.45	7.59	6.00	2.40	3.70	silty clay loam
168	F3/2/21	626490	1024333	22-Apr-04	30-60	8.55	2.02	11.24	7.29	1.91	5.24	clay
169	F1/2D/67	625053	1026823	21-Apr-04	0-30	8.64	0.77	5.62	1.35	0.81	5.41	silty clay
170	F3/2/21	626490	1024333	22-Apr-04	0-30	8.76	1.13	8.15	2.43	1.17	6.07	silty clay loam
171	F10/2/12	634183	1041262	26-Apr-04	0-30	8.49	0.94	6.06	2.67	1.60	4.15	silty clay loam
172	F5B/10B	630820	1032636	28-Apr-04	0-30	8.41	1.30	7.47	4.93	1.87	4.05	silty clay loam
173	F11/3/2	632876	1038319	24-Apr-04	0-30	8.51	0.53	4.65	0.93	0.27	6.01	clay
174	F11/8/14	635980	1042204	27-Apr-04	0-30	8.45	0.52	4.65	0.49	0.18	8.06	clay
175	F4/1/1B	628674	1026358	23-Apr-04	0-30	8.15	0.76	6.06	1.33	0.80	5.87	silt loam
176	F3/2/25	626947	1025168	22-Apr-04	0-30	8.49	0.68	5.64	0.93	0.80	6.06	silt loam
177	F1/3/37	622116	1028186	20-Apr-04	0-30	8.10	0.87	6.20	2.13	0.53	5.37	silty clay
178	F3/2/28	627396	1025709	22-Apr-04	0-30	8.45	0.61	5.36	0.27	1.07	6.56	silt loam
179	F11/7/5	635759	1040725	27-Apr-04	0-30	8.24	0.72	5.64	0.93	1.20	5.46	clay
180	F3/2/30	627034	1026523	22-Apr-04	0-30	8.36	0.63	4.79	0.40	1.73	4.64	clay
181	7th Camp	621858	1027279	21-Apr-04	0-30	8.03	14.51	28.66	80.25	31.19	3.84	silt
182	F3/3/41	627030	1026768	22-Apr-04	0-30	8.26	1.06	7.19	2.27	2.13	4.85	clay
183	1A6	622781	1022667	19-Apr-04	0-30	8.46	0.93	7.61	2.00	0.27	7.15	silt loam
184	F11/2/1	631940	1038541	24-Apr-04	0-30	8.27	0.58	5.64	0.27	0.27	10.92	clay
185	4B10	624877	1026070	20-Apr-04	0-30	8.47	1.98	7.90	9.46	3.07	3.15	clay loam
186	F3/1/10	627443	1024069	21-Apr-04	0-30	8.35	0.85	7.05	0.27	0.93	9.10	sandy clay loam
187	F1/1/10	621347	1024029	20-Apr-04	0-30	7.92	74.00	245.72	329.92	166.49	15.60	silt loam
188	F4/3/18	628481	1028204	23-Apr-04	0-30	8.50	0.81	6.06	2.00	0.80	5.12	silty clay loam
189	F6/26	633585	1037214	29-Apr-04	0-30	8.36	0.76	6.77	0.93	0.27	8.74	clay
190	F1/2D/64	624542	1027462	21-Apr-04	0-30	7.98	11.58	61.22	41.19	11.46	11.93	clay loam
191	Cold Store	624990	1024158	20-Apr-04	0-30	8.09	13.50	89.27	27.59	13.60	19.67	silt loam
192	F3/1/1	625990	1022439	21-Apr-04	0-30	8.35	1.51	11.84	2.80	0.93	8.67	loam
193	F11/4/2	633929	1038371	24-Apr-04	0-30	8.04	0.67	5.92	0.93	0.27	7.65	clay
194	F3/4/50	625794	1027941	22-Apr-04	0-30	8.21	1.12	7.19	4.00	0.53	4.78	clay
195	F4/1/2B	628832	1026767	23-Apr-04	0-30	8.21	1.07	6.35	3.20	1.07	4.34	silty clay
196	F10/2/8	633449	1040062	26-Apr-04	0-30	8.26	0.77	6.49	0.98	0.82	6.84	clay
197	F3/3/43	626501	1027488	22-Apr-04	0-30	8.31	0.73	6.49	0.93	0.27	8.37	clay
198	F1/3/34	621769	1027348	21-Apr-04	0-30	8.12	9.53	31.04	43.59	22.13	5.41	silty clay
199	1C1#2	623129	1021100	19-Apr-04	0-30	8.49	0.74	6.22	1.47	0.53	6.22	clay
200	F5B/25	634620	1036646	26-Apr-04	0-30	8.25	0.94	8.04	0.49	0.18	13.92	clay

Sampled by: Gedion Tsegaye Sahle (AAU, School of Graduate Studies, MSc. Hydrogeology Stream); Laboratory Analyses: in May-June 2004, by Gedion Tsegaye & EARO - Werer Research Center Staff

Annex 5e Amibara Soil Database (This Study)

Lab No.	Field Code	UTM Easting	UTM Northing	Sampling Date	Depth (cm)	pHe	ECe (mS/cm)	Na (meq/l)	Ca (meq/l)	Mg (meq/l)	SARe	Textural Class
201	F11/4/5	634117	1039063	24-Apr-04	0-30	8.46	0.76	5.56	1.54	1.13	4.81	clay
202	F6/15	632468	1035188	24-Apr-04	0-30	8.51	0.65	4.55	1.89	0.51	4.15	clay
203	F3/1/13	627903	1024646	21-Apr-04	0-30	8.74	0.76	5.96	2.40	0.27	5.16	loam
204	1C2	623236	1021452	19-Apr-04	0-30	8.76	0.61	5.05	1.54	0.26	5.32	silt loam
205	F3/1/18	628400	1025723	21-Apr-04	0-30	8.59	0.84	6.36	1.33	1.07	5.81	clay
206	F3/1/14	628022	1024832	21-Apr-04	0-30	8.29	2.41	5.96	12.18	5.82	1.99	clay loam
207	F3/1/9	627177	1023943	21-Apr-04	0-30	8.61	0.90	5.45	3.47	2.80	3.08	clay loam
208	F11/2/2#2	632335	1039374	24-Apr-04	0-30	8.63	0.88	5.56	2.27	0.80	4.49	silt loam
209	F3/1/12	627748	1024363	21-Apr-04	0-30	8.31	10.72	46.96	43.59	16.26	8.58	loam
210	F3/1/8	627033	1023774	21-Apr-04	0-30	8.56	1.90	8.08	8.53	5.20	3.08	clay loam
211	F1/2B/55	622511	1026405	21-Apr-04	0-30	8.45	0.73	4.95	1.05	1.35	4.52	silty clay
212	F3/2/19	626164	1023974	22-Apr-04	0-30	8.17	12.56	33.43	45.06	26.26	5.60	silt loam
213	F3/4/52	625835	1028476	22-Apr-04	0-30	8.28	0.69	4.85	1.89	0.78	4.20	clay
214	F3/1/15	628141	1025076	21-Apr-04	0-30	8.29	0.84	6.26	2.27	0.80	5.06	clay loam
215	F1/2B/77	625550	1028387	21-Apr-04	0-30	8.43	0.88	4.85	3.60	1.47	3.05	clay
216	2B12	622254	1024476	19-Apr-04	0-30	8.56	0.85	4.44	3.47	0.93	3.00	clay
217	F11/7/1	636310	1040072	27-Apr-04	0-30	8.38	0.58	4.44	2.27	0.13	4.06	clay
218	Grass Land	624098	1022597	19-Apr-04	0-30	8.09	69.20	621.22	43.19	26.13	105.52	silt loam
219	F3/1/6	626660	1023424	21-Apr-04	0-30	8.58	1.55	8.28	3.33	1.87	5.14	silty clay loam
220	1C8	623489	1022386	19-Apr-04	0-30	8.83	1.16	7.27	4.40	1.20	4.35	silty clay loam
221	1C3	623282	1021737	19-Apr-04	0-30	8.38	1.11	5.76	4.40	1.60	3.32	silty clay loam
222	Forest Area	623880	1027397	21-Apr-04	0-30	8.55	1.35	4.65	6.93	2.13	2.18	clay
223	1B7	623004	1023140	19-Apr-04	0-30	8.65	0.68	3.94	2.80	0.53	3.05	silty clay loam
224	1A10	622484	1024055	19-Apr-04	0-30	8.60	1.40	5.96	6.67	0.67	3.11	silty clay
225	2D20	623436	1024999	20-Apr-04	0-30	8.61	0.66	3.94	3.20	1.20	2.66	silty clay loam
226	F3/4/48	625736	1027466	22-Apr-04	0-30	8.43	0.88	5.66	3.60	0.27	4.07	silt loam
227	4C10	625588	1025213	20-Apr-04	0-30	8.04	9.15	33.43	48.25	11.73	6.10	silt loam
228	F3/2/22	626532	1024559	22-Apr-04	0-30	8.67	0.71	4.34	2.80	0.27	3.51	silty clay
229	F4/2/11#1	627706	1027250	23-Apr-04	0-30	8.77	0.76	6.77	0.49	0.16	11.87	silty clay loam
230	1A1	622334	1021308	19-Apr-04	0-30	8.72	1.15	6.16	5.60	0.53	3.52	silty clay loam
231	1C1 #3	623210	1021366	19-Apr-04	0-30	8.76	1.00	4.24	3.47	1.87	2.60	silty clay loam
232	F11/3/4	633353	1038192	24-Apr-04	0-30	8.45	0.64	3.94	1.07	2.00	3.18	clay
233	F6/27B #2	634295	1037736	29-Apr-04	0-30	8.60	0.99	7.37	1.47	0.67	7.14	silty clay
234	F11/2/1#2	632237	1039409	24-Apr-04	0-30	8.61	1.22	6.97	4.00	2.27	3.94	silt loam
235	F10/2/9	633494	1040389	26-Apr-04	0-30	8.67	0.76	5.86	1.87	0.40	5.50	silty clay loam
236	F11/1/3 #2	631975	1039101	24-Apr-04	0-30	8.58	4.02	23.08	16.26	3.47	7.35	silt loam
237	F10/6/3	633280	1041433	26-Apr-04	0-30	8.35	2.19	8.28	8.00	3.33	3.48	silt loam
238	F6/12	631534	1034889	24-Apr-04	0-30	8.58	0.70	5.15	1.33	1.07	4.70	silt loam
239	F4/2/12	627888	1027968	23-Apr-04	0-30	8.62	0.99	5.66	2.93	0.93	4.07	silt loam
240	4B4	625197	1024061	20-Apr-04	0-30	8.72	0.86	5.96	1.47	1.33	5.04	silty clay loam
241	F10/9/4	633823	1042945	27-Apr-04	0-30	8.32	2.27	8.38	11.86	1.07	3.30	silt loam
242	F10/2/5	633370	1039616	26-Apr-04	0-30	8.58	0.60	4.55	0.93	0.80	4.88	silty clay
243	F10/9/5	633708	1043055	27-Apr-04	0-30	8.67	0.83	5.66	1.87	0.80	4.90	silt loam
244	F10/2/4	633204	1039725	26-Apr-04	0-30	8.60	0.59	4.14	0.80	1.33	4.01	silty clay loam
245	F3/1/3	626233	1022730	21-Apr-04	0-30	8.67	0.78	5.35	2.40	1.07	4.07	loam
246	F10/7/3	633354	1041945	27-Apr-04	0-30	7.88	22.70	38.21	96.78	93.44	3.92	silt loam
247	F5B/20B #2	633351	1036140	26-Apr-04	0-30	8.13	11.89	34.27	62.78	17.86	5.40	clay loam
248	F11/1/3	631371	1039283	24-Apr-04	0-30	8.52	2.68	10.10	13.20	3.60	3.49	silty clay loam
249	F6/19	632481	1035350	24-Apr-04	0-30	8.53	0.68	3.94	3.07	0.40	2.99	clay
250	F11/4/3	633948	1038630	24-Apr-04	0-30	8.63	0.76	5.05	2.53	0.27	4.27	clay

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Annex 5f Amibara Soil Database (This Study)

Lab No.	Field Code	UTM Easting	UTM Northing	Sampling Date	Depth (cm)	pHe	ECe (mS/cm)	Na (meq/l)	Ca (meq/l)	Mg (meq/l)	SARe	Textural Class
251	F3/2/27	626603	1025920	22-Apr-04	0-30	8.43	0.87	4.24	4.53	1.33	2.48	clay
252	F3/3/35	626251	1025519	22-Apr-04	0-30	8.37	0.83	4.44	2.80	1.87	2.91	silty clay
253	F6/23B	633209	1036927	24-Apr-04	0-30	8.30	6.98	34.23	31.06	3.74	8.21	clay
254	F10/4/3	632618	1040791	26-Apr-04	0-30	8.43	0.84	4.14	2.80	1.47	2.84	silty clay loam
255	F5B/26	634749	1036860	26-Apr-04	0-30	8.47	0.62	3.64	2.80	0.27	2.94	clay
256	F1/2B/58	622999	1026930	21-Apr-04	0-30	8.42	0.92	4.44	3.33	2.00	2.72	clay
257	F11/1/2	631231	1039047	24-Apr-04	0-30	8.57	0.67	3.74	2.53	0.13	3.24	silty clay loam
258	F10/2/6	633537	1039223	26-Apr-04	0-30	8.40	0.71	5.35	2.13	0.40	4.76	clay
259	F11/7/7	635800	1041091	27-Apr-04	0-30	8.36	0.77	3.43	2.93	1.47	2.32	clay
260	4A7	624753	1025167	20-Apr-04	0-30	8.40	5.37	31.84	22.22	3.77	8.83	silt loam
261	F6/18	632254	1035375	24-Apr-04	0-30	8.43	1.36	7.68	4.00	1.07	4.82	clay
262	F11/5/2	635252	1039084	27-Apr-04	0-30	8.61	0.65	4.65	2.13	0.27	4.24	clay
263	F3/1/3#2	626377	1022741	21-Apr-04	0-30	8.14	10.70	72.27	22.66	5.47	19.27	sandy clay loam
264	F4/2/13	627295	1027824	23-Apr-04	0-30	8.44	0.72	5.56	1.73	0.80	4.94	silty clay
265	F11/1/4#2	632029	1039312	24-Apr-04	0-30	8.13	9.74	47.76	34.52	13.60	9.74	clay loam
266	F1/1/17	621979	1025519	21-Apr-04	0-30	8.57	0.90	6.87	2.13	0.40	6.10	clay
267	F4/1/5B	629404	1027661	23-Apr-04	0-30	8.48	0.90	5.76	3.47	1.20	3.77	clay
268	F10/2/2	631810	1039816	26-Apr-04	0-30	8.13	5.98	23.88	31.86	6.13	5.48	silty clay loam
269	F4/1/10B	630160	1029198	23-Apr-04	0-30	8.57	0.68	4.14	2.13	0.53	3.59	silty clay
270	F6/14B	632228	1035160	24-Apr-04	0-30	8.55	0.80	4.65	2.67	1.07	3.40	clay
271	F11/1/4	631586	1039471	24-Apr-04	0-30	8.55	0.94	5.15	3.20	0.53	3.77	clay loam
272	F10/2/7	633753	1039138	26-Apr-04	0-30	8.61	0.59	3.43	1.73	0.40	3.33	clay
273	F10/2/11	634153	1041393	26-Apr-04	0-30	8.63	0.68	3.94	2.40	0.40	3.33	silty clay
274	F11/4/1	633829	1038161	24-Apr-04	0-30	8.46	0.61	3.13	0.40	2.27	2.71	clay
275	F6/13	631795	1034972	24-Apr-04	0-30	8.53	0.64	3.23	2.67	1.07	2.37	silty clay loam
276	F11/3/5 #1	633609	1038210	24-Apr-04	0-30	8.55	0.68	3.43	2.67	0.67	2.66	clay
277	F11/3/1	632667	1038441	24-Apr-04	0-30	8.49	0.69	5.25	2.27	0.40	4.55	clay
278	F6/16	631750	1035363	24-Apr-04	0-30	8.45	0.67	3.84	3.47	0.27	2.81	clay
279	F11/8/1	636800	1041185	28-Apr-04	0-30	8.49	0.75	4.24	2.00	0.80	3.59	clay
280	F11/3/5 #2	633923	1038910	24-Apr-04	0-30	8.52	0.74	3.94	2.40	0.53	3.25	silty clay loam
281	F10/6/1	632915	1041110	26-Apr-04	0-30	8.26	4.03	12.61	34.00	9.60	2.70	silty clay loam
282	2A8	624357	1023697	19-Apr-04	0-30	8.34	5.43	26.27	29.33	0.27	6.83	clay
283	F6/28B	634533	1036928	26-Apr-04	0-30	8.68	0.86	5.18	2.53	1.07	3.86	clay
284	F4/1/8	630196	1028421	23-Apr-04	0-30	8.63	1.08	5.86	4.53	1.07	3.50	silty clay
285	F4/3/16B	628537	1027172	23-Apr-04	0-30	8.57	1.52	6.05	8.13	1.73	2.72	silty clay loam
286	F6/27B	634081	1037098	29-Apr-04	0-30	8.69	1.10	5.76	5.20	0.67	3.36	silty clay
287	PK2	625530	1022498	22-Apr-04	0-30	8.86	1.30	7.49	2.27	2.53	4.83	silty clay
288	F1/2B/49	622589	1026658	21-Apr-04	0-30	8.59	1.17	5.86	4.00	2.53	3.24	clay
289	F9/3/24C	633494	1037606	30-Apr-04	0-30	8.65	0.77	4.70	3.20	0.27	3.57	silty clay
290	1A1/4	628185	1035202	3-May-04	0-30	8.55	0.59	3.26	2.00	0.93	2.70	silty clay loam
291	C6/1	628720	1036566	4-May-04	0-30	8.63	0.84	4.90	2.93	1.60	3.25	silty clay loam
292	C6/7B	629095	1037220	4-May-04	0-30	8.41	0.70	4.42	2.40	0.53	3.65	clay
293	B1/1	627680	1036859	3-May-04	0-30	8.61	0.71	4.61	1.87	1.07	3.81	silty clay loam
294	F10/8/7	635368	1041362	27-Apr-04	0-30	8.35	0.72	4.80	1.73	1.20	3.96	loam
295	D2/14	630929	1034708	1-May-04	0-30	8.38	0.85	6.24	1.87	1.07	5.15	silty clay
296	F9/1/3	631188	1036714	1-May-04	0-30	8.59	0.61	4.32	1.47	0.80	4.06	clay
297	F9/3/19	632510	1037922	30-Apr-04	0-30	8.55	0.76	4.99	2.40	1.07	3.79	silty clay
298	F10/5/4	632849	1041654	16-May-04	0-30	8.01	7.22	26.27	39.19	3.73	5.67	clay loam
299	F11/5/4	634770	1039203	27-Apr-04	0-30	8.59	0.90	5.38	3.47	0.27	3.94	silt loam
300	F9/3/20B	632720	1037415	30-Apr-04	0-30	8.14	2.89	7.58	14.13	2.13	2.66	clay

Sampled by: Gedion Tsegaye Sahle (AAU, School of Graduate Studies, MSc. Hydrogeology Stream); Laboratory Analyses: in May-June 2004, by Gedion Tsegaye & EARO - Werer Research Center Staff

Annex 5g Amibara Soil Database (This Study)

Lab No.	Field Code	UTM Easting	UTM Northing	Sampling Date	Depth (cm)	pHe	ECe (mS/cm)	Na (meq/l)	Ca (meq/l)	Mg (meq/l)	SARe	Textural Class
301	D4/7A	630261	1038785	3-May-04	0-30	8.41	1.19	5.57	4.93	1.33	3.15	silt loam
302	ER/113	628146	1032536	10-May-04	60-90	8.22	2.22	8.83	8.40	2.27	3.82	clay
303	MMP/2B	629206	1035278	4-May-04	0-30	8.63	0.81	5.47	1.87	1.60	4.16	clay
304	D2/15	630777	1034951	30-Apr-04	0-30	8.52	0.87	5.28	2.13	1.73	3.80	clay loam
305	ER/201	629266	1032117	10-May-04	0-30	8.44	0.68	4.61	2.53	0.40	3.81	silty clay loam
306	30H/B	628194	1034497	4-May-04	0-30	8.51	0.80	4.51	2.80	1.47	3.09	silty clay loam
307	B1/2	628276	1036717	3-May-04	0-30	8.47	0.71	3.94	1.87	1.47	3.05	silty clay
308	F9/3/8	631008	1037934	30-Apr-04	0-30	7.75	42.27	149.64	201.27	70.53	12.84	silt loam
309	ER cpd 1	629296	1031800	11-May-04	0-30	8.68	0.67	5.09	1.73	0.93	4.41	silty clay loam
310	F9/3/14	631699	1038088	30-Apr-04	0-30	8.48	1.07	5.76	4.00	2.27	3.25	silty clay loam
311	D4/8B	629432	1038564	3-May-04	0-30	8.57	0.77	4.99	2.80	3.20	2.88	clay
312	AL 7/10	629650	1040907	5-May-04	0-30	8.50	0.90	5.38	3.33	1.20	3.57	clay
313	F10/3/2	631964	1040619	16-May-04	0-30	7.92	14.12	35.82	81.31	18.93	5.06	loam
314	F9/3/7	630860	1037921	30-Apr-04	0-30	7.97	5.70	23.08	29.33	5.87	5.50	clay loam
315	F5B/23A	634135	1036214	26-Apr-04	0-30	8.66	0.83	5.57	2.00	1.47	4.23	clay
316	1A1/1	627623	1035256	3-May-04	0-30	8.57	1.22	5.86	5.20	1.07	3.31	silty clay loam
317	F5B/3	630881	1031139	28-Apr-04	0-30	8.58	0.81	5.18	2.40	1.07	3.94	clay
318	ER/205	629012	1032334	10-May-04	0-30	8.37	1.10	6.24	2.53	1.73	4.27	silt loam
319	AL 11/5	630274	1041190	5-May-04	0-30	8.44	0.76	3.94	3.20	0.93	2.74	clay
320	F5B/12A	631659	1033655	28-Apr-04	0-30	8.51	0.64	4.22	1.73	0.53	3.97	clay
321	F11/8/8	637357	1042478	27-Apr-04	0-30	7.90	0.88	6.24	1.33	0.67	6.24	silty clay
322	1A2 /3	628018	1035663	3-May-04	0-30	7.92	1.21	5.09	6.40	1.20	2.61	silty clay loam
323	F9/3/2	630493	1038221	30-Apr-04	0-30	7.14	22.30	46.17	121.70	54.25	4.92	silt loam
324	F11/6/4	635128	1039870	27-Apr-04	0-30	7.91	0.85	5.28	2.80	1.07	3.80	silty clay loam
325	D4/5	629044	1038273	3-May-04	0-30	8.41	0.84	6.05	2.67	0.67	4.69	silty clay
326	MMP/8B	629364	1037654	3-May-04	0-30	8.24	0.73	5.09	1.73	1.47	4.02	silty clay loam
327	F5A/7A	631096	1031178	28-Apr-04	0-30	8.25	0.80	6.05	1.60	0.40	6.05	clay
328	ER/300#1	629209	1032736	10-May-04	0-30	7.93	0.57	5.38	1.20	0.80	5.38	clay
329	F9/3/12#2	631116	1038405	30-Apr-04	0-30	7.85	5.86	27.86	29.33	3.60	6.87	loam
330	B7/8	627469	1038946	4-May-04	0-30	7.80	0.73	5.09	1.33	0.80	4.93	clay loam
331	F5A/4B	631048	1029863	28-Apr-04	0-30	7.95	0.76	5.18	1.20	1.20	4.73	silty clay
332	D4/9	629729	1038800	3-May-04	0-30	7.99	0.83	5.66	2.67	0.53	4.48	silty clay
333	F9/2/4	631533	1037290	30-Apr-04	0-30	7.84	0.80	7.30	1.07	0.27	8.94	clay
334	B1/0/P	627316	1036918	3-May-04	0-30	8.07	0.67	4.61	1.73	0.93	3.99	clay loam
335	F9/3/12	630856	1038386	30-Apr-04	0-30	7.80	4.44	25.47	15.46	3.60	8.25	loam
336	F5A/6A	630862	1030903	28-Apr-04	0-30	7.95	0.89	5.76	2.13	1.87	4.07	clay
337	1A2/0/P	627498	1035738	3-May-04	0-30	8.07	0.94	5.76	3.87	0.93	3.72	silty clay loam
338	F5B/9	630343	1031939	7-May-04	0-30	8.10	0.87	5.66	2.93	1.33	3.88	clay loam
339	B3/4	628434	1037879	3-May-04	0-30	7.72	0.82	5.18	3.33	0.80	3.61	silty clay
340	F10/1/2	630804	1039158	16-May-04	0-30	7.67	6.42	24.68	31.19	8.66	5.53	silt loam
341	B2/5	628646	1037076	3-May-04	0-30	7.85	0.88	5.18	4.00	0.40	3.50	silty clay loam
342	F10/9/3	634096	1042808	27-Apr-04	0-30	7.90	0.64	4.70	1.33	1.33	4.07	loam
343	F6/2B	629969	1033510	1-May-04	0-30	7.71	1.08	6.14	3.87	1.47	3.76	loam
344	AL 10/1	628914	1041598	5-May-04	0-30	7.86	0.85	5.09	3.20	1.73	3.24	clay
345	AB/4	630208	1034431	7-May-04	0-30	7.92	1.82	7.10	11.06	3.47	2.64	clay loam
346	F11/7/9	636156	1041425	27-Apr-04	0-30	7.67	0.89	5.57	0.93	1.47	5.08	clay
347	C6/14	629104	1037828	3-May-04	0-30	7.50	0.68	4.80	1.47	0.80	4.51	silty clay loam
348	F5B/10B	630820	1032636	28-Apr-04	30-60	7.55	1.88	7.97	7.60	4.27	3.27	silty clay
349	F5B/18	633012	1035124	26-Apr-04	0-30	8.03	1.12	6.24	2.13	2.80	3.97	clay
350	ER/127	627366	1033306	10-May-04	0-30	7.54	8.27	32.64	42.39	9.20	6.43	silty clay loam

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Annex 5h Amibara Soil Database (This Study)

Lab No.	Field Code	UTM Easting	UTM Northing	Sampling Date	Depth (cm)	pHe	ECe (mS/cm)	Na (meq/l)	Ca (meq/l)	Mg (meq/l)	SARe	Textural Class
351	1A2/6	628396	1035703	3-May-04	0-30	8.25	0.88	6.05	2.53	0.53	4.88	clay
352	F6/6B	630828	1033134	28-Apr-04	0-30	8.23	1.07	6.82	3.07	1.20	4.67	clay
353	AM/ZR	631770	1042023	6-May-04	0-30	7.77	2.11	7.49	10.26	4.40	2.77	clay loam
354	F3/3/34	625573	1025902	22-Apr-04	0-30	8.22	0.82	5.76	1.33	1.20	5.12	silty clay
355	F6/9	631417	1034270	28-Apr-04	0-30	8.03	0.71	5.18	1.60	1.33	4.28	silty clay
356	D4/10	629338	1038868	3-May-04	0-30	7.75	0.69	4.90	2.00	0.80	4.14	silty clay
357	F10/2/8#2	634314	1039745	29-Apr-04	0-30	7.98	0.75	5.57	2.27	0.53	4.71	silty clay
358	F9/3/1	630277	1037491	30-Apr-04	0-30	7.54	16.84	42.19	90.38	31.46	5.41	silt loam
359	F9/2/5	631220	1037491	30-Apr-04	0-30	8.06	1.22	7.01	3.60	1.73	4.29	silty clay loam
360	D2/20	631357	1035006	1-May-04	90-120	7.44	9.80	44.27	37.86	12.66	8.81	silt loam
361	BA/2	633968	1044460	6-May-04	60-90	8.01	0.90	5.86	1.47	2.13	4.37	silty clay loam
362	F10/10/4	635197	1042379	27-Apr-04	0-30	8.46	0.89	7.24	1.87	0.27	7.01	clay
363	F9/3/3	630404	1038078	30-Apr-04	0-30	7.74	58.54	401.07	140.76	39.06	42.30	silt loam
364	F5B/6B	630864	1032526	28-Apr-04	0-30	8.18	1.01	8.26	1.07	0.93	8.26	clay
365	F9/3/24A	633048	1037628	30-Apr-04	0-30	8.46	0.88	6.30	2.40	0.53	5.20	silty clay
366	ER/225	627780	1033480	10-May-04	0-30	8.72	0.87	6.43	2.53	0.80	4.98	silty clay
367	F5A/9B	631138	1031354	28-Apr-04	0-30	8.45	0.94	7.10	2.80	1.20	5.02	clay
368	D4/6/P	630060	1038099	3-May-04	0-30	8.36	0.77	5.76	1.33	1.07	5.26	silty clay loam
369	F9/3/13B	631563	1037909	30-Apr-04	0-30	7.91	0.76	6.14	1.87	0.27	5.95	silty clay
370	D2/12	630719	1035623	1-May-04	0-30	8.20	0.96	5.76	3.73	1.07	3.72	clay
371	F10/10/6	635605	1042246	27-Apr-04	0-30	8.41	1.12	7.50	3.07	1.33	5.06	clay
372	F5A/10	631340	1032539	28-Apr-04	0-30	8.37	0.82	8.21	1.07	0.27	10.06	clay
373	ER/230	627458	1033770	10-May-04	0-30	8.39	0.93	6.24	2.13	1.47	4.65	silty clay
374	AB/6	629959	1030176	7-May-04	0-30	8.39	0.74	4.80	2.00	1.07	3.88	silty clay loam
375	F5B/13	632170	1033538	28-Apr-04	0-30	8.43	0.81	5.47	2.00	1.20	4.33	clay
376	1A3/5	628317	1036370	3-May-04	0-30	8.27	0.71	4.61	2.00	1.20	3.64	clay
377	F1/1/1	621770	1022720	20-Apr-04	0-30	8.09	1.27	6.43	4.40	1.07	3.89	clay
378	D4/1B	629884	1037933	3-May-04	0-30	8.47	0.93	5.76	2.67	1.73	3.88	silty clay loam
379	F9/3/4	630414	1037830	30-Apr-04	0-30	7.80	11.60	35.02	56.92	25.59	5.45	silt loam
380	F9/3/18A	632105	1037390	30-Apr-04	0-30	8.47	0.81	5.28	1.73	1.87	3.94	clay
381	F11/7/3	636071	1040388	27-Apr-04	0-30	8.47	0.71	4.80	1.60	1.07	4.16	clay
382	AM/GE/3	630392	1042936	7-May-04	0-30	8.58	0.87	5.76	1.60	1.60	4.55	silty clay
383	F10/2/10#2	634456	1040040	29-Apr-04	0-30	8.22	1.59	7.10	6.67	1.33	3.55	clay
384	F11/8/10	636951	1042370	27-Apr-04	0-30	8.42	0.97	5.95	1.73	2.00	4.36	silty clay
385	D2/17	630932	1035890	1-May-04	0-30	8.45	0.76	4.99	1.60	1.60	3.95	clay
386	D2/3	629884	1035818	1-May-04	0-30	8.27	0.80	5.38	2.53	0.93	4.08	silty clay
387	1A3/2	627924	1036577	3-May-04	30-60	8.38	0.81	5.09	1.33	0.93	4.78	clay
388	F10/2/14	634906	1041243	27-Apr-04	0-30	8.30	0.71	4.99	1.07	0.53	5.58	silty clay loam
389	F6/24	633455	1037072	29-Apr-04	0-30	8.27	1.71	7.39	6.53	2.27	3.52	clay
390	AL 2/6	628883	1039908	5-May-04	0-30	8.13	1.82	7.01	7.60	1.87	3.22	silty clay loam
391	F9/3/6	630615	1038009	30-Apr-04	0-30	7.77	13.90	42.21	76.51	15.46	6.22	silty clay loam
392	F5B/17	632763	1035069	26-Apr-04	0-30	8.43	1.08	5.95	2.40	1.47	4.28	clay
393	F11/7/9	636156	1041425	27-Apr-04	90-120	8.39	1.53	7.39	4.40	2.40	4.01	clay
394	AL 11/1	629926	1041326	5-May-04	0-30	8.19	1.62	5.86	7.20	2.13	2.71	clay
395	F10/9/1	634430	1042628	27-Apr-04	0-30	8.42	0.86	5.47	2.00	1.07	4.42	clay
396	D3/2/1	630092	1036294	1-May-04	0-30	7.59	37.07	133.72	194.88	32.13	12.55	silt loam
397	F11/7/11	636560	1041801	27-Apr-04	0-30	8.25	0.84	5.09	2.27	0.67	4.20	silty clay
398	B2/3	628707	1037835	3-May-04	0-30	8.27	0.79	5.09	2.80	0.80	3.79	silty clay loam
399	F4/3/15A	627999	1026757	23-Apr-04	0-30	8.13	1.67	6.72	6.00	2.67	3.23	silty clay loam
400	F11/1/1	631044	1038938	24-Apr-04	0-30	8.41	0.87	5.76	1.87	0.67	5.12	silty clay loam

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Annex 5i Amibara Soil Database (This Study)

Lab No.	Field Code	UTM Easting	UTM Northing	Sampling Date	Depth (cm)	pHe	ECe (mS/cm)	Na (meq/l)	Ca (meq/l)	Mg (meq/l)	SARe	Textural Class
401	F9/3/18B	632390	1037500	30-Apr-04	0-30	8.39	0.65	4.70	0.80	0.40	6.07	clay
402	F5B/19 #1	633096	1035274	26-Apr-04	0-30	8.27	0.62	4.80	1.07	0.40	5.61	clay
403	AB/3	629716	1033922	7-May-04	0-30	8.25	1.97	8.16	7.73	3.07	3.51	loam
404	ER/300#2	629222	1033182	10-May-04	0-30	8.33	0.69	3.74	3.33	0.53	2.69	silty clay
405	F5A/8B	631543	1031307	28-Apr-04	0-30	7.73	1.84	7.39	7.60	2.27	3.33	clay
406	AM/GE/1	632816	1045117	7-May-04	0-30	8.43	1.77	8.64	5.07	3.47	4.18	clay
407	F9/1/2B	631289	1036332	1-May-04	0-30	8.05	0.68	4.51	2.13	0.80	3.73	silty clay
408	AM/GE/2	633503	1043378	7-May-04	0-30	7.68	20.10	70.04	109.04	24.93	8.56	silt loam
409	F9/3/11	631095	1038246	30-Apr-04	0-30	7.98	11.96	48.22	62.52	11.73	7.91	silty clay loam
410	F5B/19#2	633676	1035811	26-Apr-04	0-30	8.34	1.48	7.01	5.87	0.80	3.84	clay
411	F5B/2	630198	1030874	28-Apr-04	0-30	8.46	0.77	5.09	2.13	0.80	4.20	silty clay
412	F5B/23B	634296	1036337	26-Apr-04	0-30	8.40	0.95	5.57	2.93	0.80	4.08	clay
413	F9/3/5	630644	1038353	30-Apr-04	0-30	7.79	4.62	11.04	24.93	10.80	2.61	loam
414	C4/2	628457	1034746	4-May-04	0-30	7.80	16.47	62.08	87.18	16.40	8.63	silty clay loam
415	F10/2/10	633570	1040520	26-Apr-04	0-30	8.21	1.14	6.05	4.00	1.20	3.75	silty clay loam
416	F5B/20A #1	632938	1035474	26-Apr-04	0-30	8.14	0.82	4.80	2.67	0.27	3.96	clay
417	C6/11A	629145	1036707	4-May-04	0-30	8.03	1.08	5.86	3.20	1.07	4.01	clay loam
418	B1/5	628355	1037109	3-May-04	90-120	8.13	0.76	5.38	1.87	0.27	5.21	silty clay
419	F3/3/45	626540	1027910	22-Apr-04	0-30	8.25	0.93	5.86	2.80	0.80	4.37	silty clay
420	F5B/15	632317	1034278	28-Apr-04	0-30	8.34	1.25	6.53	3.47	1.73	4.05	clay
421	AL 3/4	627955	1040679	5-May-04	0-30	8.12	1.00	5.38	2.67	1.47	3.74	clay
422	B1/5	628355	1037109	3-May-04	0-30	7.87	0.72	5.18	2.13	0.13	4.87	silty clay loam
423	C5/6	628650	1036258	4-May-04	0-30	8.44	0.98	6.05	2.53	2.27	3.90	loam
424	D4/3	629413	1038103	3-May-04	0-30	8.72	1.43	7.68	4.67	2.27	4.13	silty clay
425	MMP/2A	629462	1034438	4-May-04	0-30	8.23	1.01	5.76	3.20	2.00	3.57	clay
426	F1/2B/75	625218	1028433	21-Apr-04	0-30	8.03	1.88	8.74	6.00	3.20	4.07	clay
427	D2/23	631528	1035724	1-May-04	0-30	8.60	1.17	7.30	2.27	1.73	5.16	clay
428	AM/GZ/1	634080	1045647	7-May-04	60-90	8.48	1.15	7.10	2.53	1.33	5.11	clay
429	F5B/20B	632777	1035637	26-Apr-04	0-30	8.38	0.99	6.05	2.67	1.20	4.35	silty clay
430	AM/GZ/2	633647	1043419	7-May-04	0-30	8.44	1.10	5.57	4.80	1.33	3.18	clay
431	F9/3/22	633102	1037976	30-Apr-04	0-30	8.35	0.82	6.01	2.28	0.72	4.91	silty clay
432	F10/8/3	634474	1042060	27-Apr-04	0-30	8.47	0.86	5.66	3.20	0.13	4.39	clay loam
433	F6/9	631417	1034270	28-Apr-04	30-60	8.22	1.01	5.47	3.52	0.75	3.74	clay
434	AL 7/4	629013	1040925	5-May-04	0-30	8.50	2.16	6.08	11.20	3.07	2.28	clay
435	F5B/21	633740	1035863	26-Apr-04	0-30	8.66	1.04	5.47	2.80	2.67	3.31	clay
436	F11/5/6	634368	1039382	27-Apr-04	0-30	8.69	1.06	5.78	3.47	2.27	3.41	clay
437	AB/1	629570	1032984	6-May-04	0-30	8.51	1.17	6.01	2.80	2.93	3.55	silty clay
438	D2/10	630733	1035916	1-May-04	0-30	8.31	2.83	5.85	19.46	3.73	1.72	silty clay
439	F11/2/2 #1	632189	1038563	24-Apr-04	0-30	8.78	1.22	6.01	3.20	1.73	3.82	clay
440	AM/ZW/2	635072	1044020	6-May-04	0-30	8.77	1.33	6.31	5.73	0.80	3.49	clay
441	B7/Z1	627610	1039268	4-May-04	0-30	8.67	0.88	5.16	2.27	0.93	4.08	silty clay loam
442	AM/KM/2	634312	1044376	6-May-04	0-30	8.44	1.19	6.39	1.87	2.27	4.45	silty clay
443	MMP/6A/P	629878	1037296	4-May-04	0-30	8.68	1.08	5.31	3.47	2.00	3.21	silt loam
444	F4/2/11#2	628164	1027496	23-Apr-04	0-30	8.61	0.82	4.39	3.60	0.80	2.96	silty clay
445	F10/2/13	634539	1041420	26-Apr-04	0-30	8.42	1.01	5.08	2.93	1.07	3.59	clay
446	AM BA/1	632930	1044262	6-May-04	0-30	8.01	3.27	9.27	15.33	7.33	2.75	silty clay
447	F5B/20A#2	633503	1035986	26-Apr-04	0-30	8.50	1.90	7.08	7.33	3.47	3.05	clay
448	F6/10B	631832	1034273	28-Apr-04	0-30	8.52	1.23	5.93	3.60	1.73	3.63	silty clay
449	F9/3/26	632154	1036919	1-May-04	0-30	8.54	0.80	5.01	2.13	0.80	4.13	clay
450	D2/20	631357	1035006	1-May-04	0-30	7.80	26.10	98.70	131.57	30.26	10.97	silt loam

Sampled by: Gedion Tsegaye Sahle (AAU, School of Graduate Studies, MSc. Hydrogeology Stream); Laboratory Analyses: in May-June 2004, by Gedion Tsegaye & EARO - Werer Research Center Staff

Annex 5j Amibara Soil Database (This Study)

Lab No.	Field Code	UTM Easting	UTM Northing	Sampling Date	Depth (cm)	pHe	ECe (mS/cm)	Na (meq/l)	Ca (meq/l)	Mg (meq/l)	SARe	Textural Class
451	F5A/11B	631726	1032536	28-Apr-04	0-30	8.62	0.84	4.54	1.73	1.47	3.59	silty clay
452	F10/4/1	632208	1040286	26-Apr-04	0-30	8.44	3.31	8.93	14.40	6.13	2.79	silty clay loam
453	MMP/6B	629602	1037301	3-May-04	0-30	8.50	1.22	5.54	4.27	3.07	2.90	silty clay
454	AM SM	632145	1044536	6-May-04	0-30	8.58	0.88	5.16	1.07	1.73	4.36	silty clay
455	F5B/1A	630277	1030479	28-Apr-04	0-30	8.54	0.81	4.39	3.47	1.07	2.92	silty clay
456	D3/3/1	630512	1037072	30-Apr-04	0-30	8.41	2.93	9.09	13.46	4.72	3.01	silty clay loam
457	AM 3/5	632298	1043401	6-May-04	0-30	8.59	0.87	4.85	1.60	1.47	3.92	silty clay loam
458	D2/10 #2	630026	1035054	1-May-04	0-30	7.45	68.54	303.27	288.46	92.78	21.97	silt loam
459	F6/1A	629893	1032616	1-May-04	0-30	8.64	0.99	5.16	2.80	1.60	3.48	clay
460	D2/11	630487	1034866	1-May-04	0-30	8.42	0.86	4.54	1.73	1.87	3.39	clay
461	F11/8/12	636472	1042306	27-Apr-04	0-30	8.37	0.81	4.54	1.20	2.00	3.59	clay
462	ER/215	628397	1032893	10-May-04	0-30	8.47	0.77	4.70	1.33	2.00	3.64	silty clay loam
463	F5B/16	632960	1034996	26-Apr-04	0-30	8.26	2.27	6.70	11.06	5.87	2.30	silty clay
464	B3/2	628408	1037554	3-May-04	0-30	8.20	1.12	4.85	3.33	2.67	2.80	silty clay
465	AL 12/3	631111	1041023	5-May-04	0-30	8.44	1.02	3.70	4.53	1.87	2.07	silty clay loam
466	F1/2A/19	622062	1025805	21-Apr-04	0-30	8.45	0.84	5.89	1.73	0.80	5.23	silty clay
467	D3/3/4	630918	1037084	30-Apr-04	30-60	7.55	154.27	82.74	45.86	19.73	14.45	loam
468	F6/8	630470	1034240	1-May-04	0-30	8.45	0.90	5.39	1.60	2.53	3.75	loam
469	AL 3/4	627955	1040679	5-May-04	30-60	8.35	1.30	6.85	2.53	2.40	4.36	clay
470	D2/20	631357	1035006	1-May-04	60-90	7.55	12.60	60.22	53.45	10.93	10.61	loam
471	4C2	625716	1023387	20-Apr-04	90-120	7.71	16.54	138.50	20.13	10.13	35.61	silty clay loam
472	AL 3/4	627955	1040679	5-May-04	60-90	8.57	1.10	8.22	2.53	0.40	6.79	silty clay
473	AN/KM/3	635082	1044732	6-May-04	30-60	8.37	1.07	5.78	3.47	2.13	3.45	silty clay loam
474	F9/3/10	631176	1038004	30-Apr-04	0-30	7.62	12.87	33.43	69.32	22.26	4.94	silt loam
475	AM AS	630988	1042675	6-May-04	60-90	8.10	1.14	5.54	3.73	1.73	3.35	silty clay loam
476	D2/20	631357	1035006	1-May-04	30-60	7.25	15.32	59.80	70.25	19.33	8.94	loam
477	F10/5/4	632849	1041654	16-May-04	60-90	7.59	4.13	25.47	14.53	2.40	8.75	silt loam
478	MMP/6B	629602	1037301	3-May-04	90-120	7.88	0.98	4.85	4.27	1.20	2.93	loam
479	F9/3/2	630493	1038221	30-Apr-04	60-90	7.13	17.76	48.22	71.45	55.05	6.06	silt loam
480	F10/6/4	633415	1041623	26-Apr-04	0-30	7.76	3.54	9.93	21.19	2.40	2.89	silty clay loam
481	F10/5/4	632849	1041654	16-May-04	90-120	7.46	3.77	9.55	21.06	5.87	2.60	silt loam
482	1A2/0/P	627498	1035738	3-May-04	90-120	7.41	2.12	5.54	14.26	2.67	1.91	silt loam
483	AM 3/7	632566	1043919	6-May-04	90-120	7.84	0.74	4.39	2.27	1.33	3.27	silty clay loam
484	MMP/6B	629602	1037301	3-May-04	60-90	7.81	0.85	4.62	3.20	1.33	3.07	silt loam
485	F10/5/4	632849	1041654	16-May-04	30-60	7.51	4.82	22.22	21.99	4.13	6.15	silt loam
486	D3/2/4	630893	1036280	1-May-04	0-30	7.31	47.10	150.45	188.22	129.03	11.95	silt loam
487	AM BE	631794	1044585	6-May-04	0-30	8.24	1.02	5.62	4.27	1.60	3.28	silt loam
488	AN/KM/3	635082	1044732	6-May-04	90-120	7.58	1.85	6.85	7.20	3.87	2.91	silty clay
489	F9/3/2	630493	1038221	30-Apr-04	90-120	7.22	16.12	36.62	72.92	35.06	4.98	silty clay
490	F9/3/2	630493	1038221	30-Apr-04	30-60	7.49	16.09	34.23	83.31	20.66	4.75	silt loam
491	MMP/6B	629602	1037301	3-May-04	30-60	7.73	1.03	4.70	5.33	2.67	2.35	silty clay
492	AM AS	630988	1042675	6-May-04	30-60	8.31	1.23	5.85	3.47	3.33	3.17	silty clay loam
493	D3/3/4	630918	1037084	30-Apr-04	90-120	7.40	7.59	22.29	43.32	7.86	4.41	sandy loam
494	B7/8	627469	1038946	4-May-04	30-60	8.12	0.90	4.54	3.20	4.27	2.35	silt loam
495	F10/7/3	633354	1041945	27-Apr-04	30-60	7.58	10.54	22.27	63.32	14.53	3.57	silt loam
496	F11/8/3	637185	1041544	28-Apr-04	60-90	8.10	0.84	4.62	3.20	1.20	3.12	silty clay
497	1A2/0/P	627498	1035738	3-May-04	30-60	7.97	0.73	4.08	3.20	0.93	2.84	silty clay loam
498	1A2/0/P	627498	1035738	3-May-04	60-90	7.41	2.59	5.31	16.53	4.00	1.66	silt
499	ER/104	628857	1032022	10-May-04	90-120	7.49	0.94	4.62	3.20	2.40	2.76	silt loam
500	F3/1/2	626093	1022555	21-Apr-04	90-120	7.46	16.67	142.22	22.53	5.07	38.29	sandy clay loam

Sampled by: Gedion Tsegaye Sahle (AAU, School of Graduate Studies, MSc. Hydrogeology Stream); Laboratory Analyses: in May-June 2004, by Gedion Tsegaye & EARO - Werer Research Center Staff

Annex 5k Amibara Soil Database (This Study)

Lab No.	Field Code	UTM Easting	UTM Northing	Sampling Date	Depth (cm)	pHe	ECe (mS/cm)	Na (meq/l)	Ca (meq/l)	Mg (meq/l)	SARe	Textural Class
501	F11/8/3	637185	1041544	28-Apr-04	30-60	7.92	0.78	3.93	2.67	0.80	2.98	clay
502	AL 5/1	629548	1040188	5-May-04	30-60	8.09	1.83	7.16	7.06	4.27	3.01	clay
503	F10/2/2	631810	1039816	26-Apr-04	30-60	7.51	9.52	23.88	55.59	11.73	4.12	silt loam
504	ER/Forest#1	627122	1032948	10-May-04	30-60	8.10	1.27	3.85	8.66	0.80	1.77	silt loam
505	AL 3/4	627955	1040679	5-May-04	90-120	8.02	0.83	5.74	2.67	0.53	4.54	sandy clay
506	2A3	624467	1023310	19-Apr-04	60-90	7.82	20.08	167.16	19.20	8.66	44.79	silty clay loam
507	ER/104	628857	1032022	10-May-04	30-60	7.90	0.98	4.85	4.13	0.53	3.18	silt loam
508	F3/1/2	626093	1022555	21-Apr-04	60-90	7.38	7.96	55.72	15.60	7.06	16.55	silt loam
509	F10/7/3	633354	1041945	27-Apr-04	90-120	7.04	10.75	59.67	39.06	5.73	12.61	loam
510	ER/Forest#1	627122	1032948	10-May-04	90-120	8.34	0.96	4.48	4.80	1.20	2.59	silt loam
511	Grassland	624098	1022597	19-Apr-04	30-60	7.80	46.07	385.56	21.73	43.46	67.54	silt loam
512	7th camp	621858	1027279	21-Apr-04	30-60	7.50	16.27	71.16	37.99	27.19	12.46	silt
513	B7/8	627469	1038946	4-May-04	90-120	7.05	5.58	30.60	20.93	2.00	9.04	silty clay loam
514	4A7	624753	1025167	20-Apr-04	90-120	7.53	13.86	104.04	19.20	9.06	27.68	silt loam
515	F4/3/18	628481	1028204	23-Apr-04	60-90	8.00	0.85	4.16	3.60	1.20	2.69	silt loam
516	F11/8/3	637185	1041544	28-Apr-04	90-120	8.01	1.18	5.52	4.53	0.67	3.42	silty clay
517	AN KM/3	635082	1044732	6-May-04	60-90	8.20	1.22	6.88	2.93	1.33	4.71	silty clay
518	F1/1/11	621325	1024221	20-Apr-04	90-120	7.54	8.83	56.62	20.66	6.40	15.39	silty clay loam
519	7th camp	621858	1027279	21-Apr-04	60-90	7.78	12.12	70.40	38.39	6.40	14.88	silt
520	AM 3/7	632566	1043919	6-May-04	30-60	8.29	1.00	4.96	2.13	2.13	3.40	silty clay loam
521	PK1	625529	1022101	22-Apr-04	30-60	9.30	9.75	94.86	2.93	1.87	61.24	silt loam
522	F1/2C/23	620933	1025399	20-Apr-04	60-90	7.60	2.10	14.24	3.60	2.93	7.88	silt
523	F10/2/2	631810	1039816	26-Apr-04	60-90	7.29	12.22	79.44	39.19	7.33	16.47	silt loam
524	4C10	625588	1025213	20-Apr-04	90-120	7.36	20.22	120.88	52.92	18.40	20.24	silt
525	7th camp	621858	1027279	21-Apr-04	90-120	7.58	15.27	95.65	51.45	5.47	17.93	clay loam
526	AL 5/1	629548	1040188	5-May-04	60-90	7.08	1.01	6.24	2.13	1.47	4.65	silty clay
527	1A1	622334	1021308	19-Apr-04	30-60	7.76	1.10	5.12	4.80	0.27	3.22	clay loam
528	AM 3/7	632566	1043919	6-May-04	60-90	8.09	1.01	4.88	1.87	2.93	3.15	silty clay loam
529	1A1	622334	1021308	19-Apr-04	60-90	7.73	1.14	5.44	2.27	2.93	3.37	silt loam
530	F4/3/18	628481	1028204	23-Apr-04	90-120	7.83	0.81	3.92	2.13	1.47	2.92	silt loam
531	Grassland	624098	1022597	19-Apr-04	60-90	7.84	19.21	172.90	11.33	9.73	53.28	silty clay loam
532	ER/Forest#1	627122	1032948	10-May-04	60-90	8.17	0.96	3.84	2.67	2.67	2.35	loam
533	4A7	624753	1025167	20-Apr-04	60-90	7.61	13.22	97.92	21.73	12.00	23.85	silt loam
534	Forest Area	623880	1027397	21-Apr-04	30-60	7.67	1.09	5.04	3.07	2.80	2.94	silty clay
535	B7/8	627469	1038946	4-May-04	60-90	7.75	2.22	12.96	5.47	2.27	6.59	silty clay loam
536	Forest Area	623880	1027397	21-Apr-04	60-90	8.15	1.01	5.04	2.27	2.40	3.30	clay
537	Cold Store	624990	1024158	20-Apr-04	30-60	7.73	17.27	139.24	24.26	7.46	34.96	silt loam
538	Forest Area	630918	1037084	30-Apr-04	60-90	7.64	8.82	57.39	24.39	6.13	14.69	sandy loam
539	4A7	624753	1025167	20-Apr-04	30-60	7.83	13.22	85.68	25.19	12.40	19.76	silt loam
540	2A3	624467	1023310	19-Apr-04	90-120	7.80	18.22	163.72	8.00	4.80	64.72	silty clay loam
541	4C10	625588	1025213	20-Apr-04	60-90	7.28	31.20	215.73	74.51	27.33	30.23	silt loam
542	F1/2C/23	620933	1025399	20-Apr-04	90-120	7.86	2.22	14.72	4.40	1.47	8.60	silt loam
543	4C2	625716	1023387	20-Apr-04	60-90	7.30	19.27	153.00	27.73	4.13	38.33	silt loam
544	4C10	625588	1025213	20-Apr-04	30-60	7.60	36.00	236.40	84.51	30.53	31.17	silt loam
545	Grassland	624098	1022597	19-Apr-04	90-120	7.58	22.27	192.78	14.13	11.06	54.32	silt loam
546	PK1	625529	1022101	22-Apr-04	90-120	9.27	3.22	26.78	2.13	1.73	19.26	clay loam
547	F10/2/2	631810	1039816	26-Apr-04	90-120	7.66	10.81	59.67	35.32	6.93	12.98	sandy loam
548	F1/1/11	621325	1024221	20-Apr-04	30-60	7.60	28.40	153.78	93.31	29.59	19.62	silt loam
549	2A3	624467	1023310	19-Apr-04	30-60	7.77	38.22	339.66	21.86	13.86	80.37	silt loam
550	F3/1/2	626093	1022555	21-Apr-04	30-60	7.89	19.19	154.36	18.93	12.93	38.68	clay loam
551	F4/3/18	628481	1028204	23-Apr-04	30-60	8.07	4.01	32.22	3.47	3.20	17.65	silty clay loam
552	F1/1/11	621325	1024221	20-Apr-04	60-90	7.61	19.63	112.47	51.45	21.73	18.59	silt loam
553	Forest Area	623880	1027397	21-Apr-04	90-120	7.86	0.91	4.80	3.87	0.93	3.10	clay
554	Cold Store	624990	1024158	20-Apr-04	60-90	7.60	19.16	153.00	24.53	11.60	36.00	silt loam
555	AM AS	630988	1042675	6-May-04	90-120	7.77	1.69	12.96	3.60	0.93	8.61	silty clay loam
556	4C2	625716	1023387	20-Apr-04	30-60	7.63	14.12	120.88	14.66	6.53	37.13	silty clay loam

Sampled by: Gedion Tsegaye Sahle (AAU, School of Graduate Studies, MSc. Hydrogeology Stream); Laboratory Analyses: in May-June 2004, by Gedion Tsegaye & EARO - Werer Research Center Staff

Declaration

I, Gedion Tsegaye Sahle, declare that this thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

Submitted by Gedion Tsegaye Sahle _____