



**Hydraulic and Hydrologic Factors on Conveyance Efficiency: Case of Fantale and Tibila Irrigation Schemes**

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**A Thesis Submitted to**

**The School of Civil and Environmental Engineering**

**Presented in Partial Fulfillment of the Requirements for the**

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**Addis Ababa University**

**Addis Ababa, Ethiopia**

**October 2013**

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## **Declaration**

I, the undersigned person, declare that this thesis is my original work and that all sources of materials used for this thesis have been duly acknowledged.

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## **Abstract**

### Hydraulic and Hydrologic Factors on Conveyance Efficiency: Case of Fantale and Tibila Irrigation Schemes

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Addis Ababa University, 2013

In planning and designing an irrigation system, a major problem is to decide what efficiency to apply in the calculations. Since basic knowledge on this subject is lacking, it is common practice that this efficiency is either assumed or derived from existing irrigation systems. Obviously, the efficiency thus obtained is unlikely to suit the conditions of the project area in its future state.

Most irrigation projects in Ethiopia are found to work below their expectation. One of the main reason behind is the difference in the conveyance & application efficiency envisioned (designed) and the actual values obtained in the projects design life. For irrigation projects having extensive length of main canal and secondary canals, the effect of conveyance efficiency is far more important than the application efficiency in deciding the project future performance.

To evaluate the effect of conveyance efficiency, variation from the designed value, two irrigation schemes, Fantale and Tibila constructed in 2003 and 2008 respectively were used as case study. The designed value was taken from the respective design reports and the existing conveyance efficiency is obtained by measuring discharge, depth of flow, wetted perimeter, wetted area and bed slope of the canal at different locations.

The conveyance efficiency given at the design stage was 95% for both schemes which was directly taken from FAO recommendations. However, the values obtained during the study were 34.4% and 89% respectively for Fantale and Tibila schemes. Such a decrease in conveyance efficiency is found to be due to hydraulic and hydrologic factors. The factor is hydraulic in a sense that the conveyance characters (roughness coefficient, hydraulic radius and bed slope) used in the designed stage has no longer exists in the current situation of the schemes. The factor is hydrologic in a sense that the variation in hydraulic radius from the designed values has resulted in increase in the water depth which intern increases the top width of the water surface which further resulted in increasing in seepage and evaporation losses.

Thus a designed conveyance efficiency taken directly from standard books has effect on the overall performance of an irrigation project. Conveyance efficiency selected should be based on construction material, method and quality, managerial activities, technological and other factors affecting conveyance efficiency.

Key words: Conveyance efficiency, Evaporation loss, Fantale & Tibila irrigation schemes

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## **List of Acronyms and Abbreviations**

BMC: Billion meter cubes

CWR: Crop Water Requirement

Ec: Conveyance Efficiency

FAO: Food and Agricultural Organization

ITCZ: Inter Tropical convergence Zone

MoWR: Ministry of Water Resources

MSF: Metahara Sugar Factory

OIDA: Oromia Irrigation Development Authority

PET: Potential Evapotranspiration

SSIP: Small-Scale Irrigation Privates

WUAs: Water Use Associations

## **1. Introduction**

McCornick et al (2003) described the effects and improvement method of use of available water resources as follows. The growing water scarcity and the misuse of available water resources are nowadays major threats to sustainable development for most river basins of Ethiopia. Different irrigation schemes did not satisfy the net irrigation demand even though the available water is more than that due to high losses from storage, conveyance, and application to irrigation plots. Identifying the various components with their level of losses and knowing what improvements can be made are essential in making most effective use of vital water resource of Awash River basin.

Improvement in conveyance efficiency will lead to improve equity in water distribution and minimize the gap between crop water requirement and actual water use. One effective approach to achieve these improvements is a good guidance for irrigation facilities, operation in institutional, managerial and technical aspects. This guidance will benefit farmers and persons/organizations in charge of water management directly.

Stakeholders complains that water stress is in increasing from year to year in Awash river basin as information obtained from staff members of supervisory bureaus which is due to irrigation inefficiency in which conveyance efficiency is one term. Therefore, the assessment of the potential cause of irrigation (conveyance) inefficiency (hydraulic and hydrologic factors) is vital for sustainable functionality of irrigation schemes in Awash River basin.

As available water resources become scarcer, more emphasis is given to efficient use of irrigation water for maximum economic return and water resources sustainability. This requires appropriate methods of measuring and evaluating how effectively water extracted from a water resource is used to produce crop yield. Inadequate irrigation application results in crop water stress and yield reduction. Excess irrigation application can result in pollution of water sources due to the loss of plant nutrients through leaching, runoff, and erosion.

The efficiency of irrigation water use varies from scheme to scheme. In schemes where water is limited, available water is used more carefully. Whereas, in areas of abundant water, the value put on conserving water is less and the tendency to over irrigate exists. Efficient use of water is also influenced by cost of labor, ease of controlling water, crops being irrigated, type of irrigation system, and soil characteristics. Various terms are used to describe how efficiently irrigation water is applied and used by crop. Incorrect usage of these terms is common and can lead to a misrepresentation of how well an irrigation system is performing.

Assessing the current situation and introducing improved techniques to manage water resources efficiently are vital for improving irrigation efficiencies, sustainability and productivity of irrigated agriculture (McCornick et al., 2003).

Therefore, two main principal factors affecting conveyance efficiency (hydraulic and hydrologic factors) were described in this research. For the assessment of the hydraulic factor, main canal discharge was taken at different locations along the canal reach for Fantale and Tibila irrigation projects, and the conveyance efficiency  $E_c$  and conveyance characteristics were calculated. The designed values for  $E_c$  and  $n$  were compared with the operational values for the two projects. The values calculated for both irrigation schemes showed that huge decrease in magnitude of  $E_c$  and increase in conveyance efficiency especially for Fantale scheme.

Again, the hydrologic factor for inefficiency was analyzed whether the river discharge was deficit or enough in meeting the crop water requirement (CWR) for the schemes and evaporation and seepage losses were evaluated.

### **1.1 Background of the study area**

Awash River Basin has a catchment area of 112,696 km<sup>2</sup>. The Awash River originates from central west part of Ethiopia, flowing 1200 km long, and provides a number of benefits to Ethiopia. Relatively the most utilized river basin and the only river entirely in the country, Awash covers the parts of the Amhara, Oromia, Afar, Somali regional states, and Dire Dawa, and Addis Ababa city administrative states of the country. The river basin has a lowest elevation of 210 m and a highest elevation of 4195 m. The total mean annual flow from the river basin is estimated to be 4.9 billion meter cubes. In this river basin 37 irrigation potential sites are identified out of which 5 are small-scale, 18 are medium-scale, and 14 are large-scale. The estimated irrigation potential is 134,125 hectares. Out of these, a potential, 30,556 hectares are for small-scale, 24,500 hectares for medium-scale and 79,065 hectares for large-scale development (Bekele et al., 2007).

Oromia is one of the largest regional states in Ethiopia with respect to population number and areal coverage. Despite of its relatively better natural setting, most part of the region is suffering from food insecurity; one third of the region is low land that is prone to drought. Due the drought and unreliability of rainfall, Fantale, Boset, Dodota-sire, Merti and Jeju were the chronically food in-secured districts in the region.

The likely hood of the community was based on Pastoral and little rain fed agriculture. However, these agricultural activities outputs were too low as results of scarcity of rainfall in the areas. Both crop & Livestock Production were not able to support the food demand of the community & hence dependent on food aid. As a result, food shortage was common year-to-year problem in the areas. Number of people affected by shortage

of food showed an increasing trend, which demands a development intervention of the the regional government. In that regard, Irrigation Based Integrated Development was found the best alternative to divert that trend and to bring radical transformation in the community tradition. Therefore, the Oromia Irrigation Development Authority / OIDA decided to intervene in the situation, through the Fentale and Tibila Irrigation Based Integrated Development Projects, that aimed to the improvement of agricultural production, with a view to realize the objective of food self-sufficiency or food security and hence improvement of social facilities.

Fentale Irrigation Based Integrated Development Project (FIBIDP) located in Fentale and Boset Woredas of East Shoa is the first farmer self-managed large-scale irrigation based development project in Oromia. It is also the first large-scale irrigation project designed and constructed by the capacity of a construction government enterprise (Oromia Water Works Construction Enterprise).

Fantale is found at a distance of 200 km Finfine / Addis Ababa and 100 km from Adama town on Asphalt road. Fentale Woreda shares borders with districts within the zone such as Boset, Arsi zone, Western Hararghe zone & Afar Region (Awash National Park). It has about 18 rural and 2 urban Kebeles. The inhabitants are kereyu and Itu Oromos in rural areas while composition of different ethnic groups in the capital of this district Metehara.

Tibila irrigation scheme is located in Oromia Regional State, Arsi administrative zone in three adjoining districts namely, Dodota-sire, Merti and Jeju. It is entirely fall in upper Awash River basin; intermingled with the existing estate and private farms. The relief of the area is dominated by flat topography bisected in to several parts by the Awash tributary Rivers.

It is situated approximately 155 km southeast of Finfinne, about 55 km from Adama town, about 15 km southwest of the Nura-era Estate farm and bounded in the North and North West by Awash River, in the south by Aseko district, in the north east by the Merti estate farm and in the west by the Hills of Merti district.

## **1.2 Statement of the Problem**

In planning and designing an irrigation system, a major problem is to decide what water use efficiency to apply in the calculations. Since basic knowledge on this subject is lacking, it is common practice that this efficiency is either assumed or derived from existing irrigation systems. Obviously, the efficiency thus obtained is unlikely to suit the conditions of the project area in its future state.

Because water use efficiency is usually the „guess“ factor in the design of an irrigation system, engineers are facing the problem of uncertainty in their calculations. To cover

this uncertainty, canals, structures and reservoirs are being given a greater capacity than would be necessary if objective efficiency standards were available and could be applied. Apart from harmful side effects, this way of doing things leads to investments that may be considerably higher than would otherwise be necessary. In another side, in irrigation schemes, high value conveyance efficiency as obtained from guidelines used in calculation gives low capacity of canals.

The lack of basic knowledge of conveyance efficiency has several serious drawbacks:

- ➡ The limited water resources are not optimally distributed and used, because of which much water goes to waste and less land can be irrigated.
- ➡ The low conveyance efficiency creates harmful side effects such as rising ground water tables and soil salinities. To control the ground water table a costly sub-surface drainage system may be necessary and this will seriously affect the economy of the project (Bos et al.,1990).

Main causes for such low conveyance efficiency would be hydrologic, hydraulic, agronomical and/or technological transfer aspects.

It would be hydrologic in the sense that the available water in the river is over or under estimated. It would be hydraulic also, where the designed hydraulic parameters over the entire irrigation system might not reflect the real parameters. Agronomic problems could be explained but are not limited to the cropping pattern and crop proposed that might not be adopted by the users. In technological transfer, if the trained farmers in the water use association failed to perform the irrigation system, the effect of technological transfer in having low irrigation efficiency is an obvious consequence.

### **Research questions**

1. Which cause of conveyance inefficiency (hydrologic or hydraulic) is seen predominant in the two irrigation schemes?
2. Based on the answer to the above question, what would be the effective strategy to tackle this main problem?
3. Which factors to be considered at study or design stage in order to decrease the gap between the values of conveyance efficiency at design and operation stages?

### **1.3. Objective**

Improvement in irrigation efficiency is one of the key factors in optimizing water use at the scheme and basin levels and to utilize limited water resources efficiently.

#### **1.3.1 General objective**

The overall objective of the study is to evaluate conveyance efficiency of Fantale and Tibila irrigation schemes in relation to hydraulic and hydrologic factors.

#### **1.3.2 Specific objectives**

- ➡ To evaluate conveyance efficiencies of the two schemes.
- ➡ To quantify the Manning's roughness coefficient, wetted perimeter and bed slope (conveyance characteristics) of Fantale and Tibila irrigation schemes.
- ➡ To analyze water budget for Fantale and Tibila irrigation schemes.
- ➡ To quantify evaporation and seepage losses from the main canal bank.
- ➡ To compare the effects of hydraulic and hydrology on the conveyance efficiency.

## **2. Literature review**

There are a lot of papers regarding the evaluation of conveyance efficiency in the literature review. But not all are exactly used since the methodologies, procedures and materials used are site and objective specific. Therefore, this thesis tried to review some papers as much as possible which are related to this topic.

### **2.1 Irrigation**

According to Yusuf (2004), irrigation is defined as the supply of water to agricultural crops by artificial means, designed to permit farming in arid regions and to offset the effect of drought in semi-arid regions. Irrigation is required even in areas where total seasonal rainfall is adequate on average, and where poorly distributed during the year and variable from year to year. Where traditional rainfed farming is a high-risk enterprise, irrigation can help to ensure stable agricultural production.

Walker (2003) stated the two primary objectives of irrigation in arid areas of the world as: (1) to supply the essential moisture for plant growth including the transport of essential nutrients; and (2) to leach or dilute salts in the soil. In addition, it stated the side benefits of irrigation such as cooling the soil and the atmosphere to create a more favorable environment for plant growth, and supplements the supply of water received from precipitation and other types of atmospheric water, floodwaters, and groundwater.

Walker (2003) also outlined the effects of the method and timing of irrigations on crop production. According to this researcher, annual crops may not germinate if the irrigation method causes a crust over the seedbed. Once established, the stress created by soil moisture tensions can often severely affect yields if they occur during critical periods. Thus, while the first objective of irrigation is to replenish the soil moisture reservoir, the method and its management are important considerations.

#### **2.1.1 Small-scale irrigation**

According to Kamara and McCornick (2012), the properly implemented smallholder irrigation with appropriate technologies may have a considerable potential in improving rural livelihoods, although the viability of such systems becomes questionable when the financial responsibility rests entirely on the community in the absence of institutional support services that enhance market orientation. These researchers also pointed out the constraints facing smallholder producers such as providing access to irrigation water, support services (access to inputs, credit, and output markets), knowledge of farming and secure land tenure. Achieving economic viability of smallholder irrigation on market-oriented basis requires access to support services and opportunities for producing high value crops. Thus, it was acknowledged that the issue of smallholder irrigation expansion should be viewed far beyond the narrow scope of just providing irrigation water and land,

to include institutional linkages, access to markets and other support services that enhance production on a sustainable basis.

### **2.1.2 Large-scale irrigation**

State run farms, which include large-scale irrigation systems, were reiterated as major components of efforts to develop the Ethiopia's down managed systems over the decades. The large-scale systems in the Awash Basin and elsewhere suffer from water management practices that have resulted in rising groundwater tables and secondary soil Salinization where large tracts of land have gone out of production. In some instances, farmers considered irrigation as an evil practice due to losses of crops and arable land resulting from bad irrigation practices. This has also been associated with conflict and water related diseases that have undermined the sustainability of such large-scale irrigation systems under the prevailing circumstances (Kamara and McCornic, 2012).

## **2.2 Irrigation potential in Ethiopia**

According to Kamara and McCornic (2012), the irrigation potential was taken as one of the most underutilized opportunities in Ethiopia. In addition, these authors pointed as the country has an irrigable land of about 3.3 million hectares of which only about 5% developed to date, with about 55% of the developed area being traditional irrigation. At the end of the 1990s, the area under small-scale irrigation was estimated at around 64 thousand hectares while that of medium and large-scale were appraised at 112 thousand hectares, of which 22 thousand hectares were new small-scale irrigation schemes implemented since 1992. The nation has a National Irrigation Development Strategy, which has the goal of utilizing the country's natural potential to achieve food self-sufficiency at the national level, generate export earnings, and provide raw materials for industry on a sustainable basis.

As Awulachew et al (2007) tried to survey on experiences and opportunities for promoting Small-scale /Micro-Irrigation and Rainwater Harvesting for food security in Ethiopia, Irrigation is one means by which agricultural production can be increased to meet the growing food demands in Ethiopia. In addition, according to these researchers, increased food demand can be met in one or a combination of three ways: increasing agricultural yield, increasing the area of arable land, and increasing cropping intensity (number of crops per year). Expansion of the area under cultivation is a finite option, especially in view of the marginal and vulnerable characteristic of large parts of the country's land. Increasing yields in both rainfed and irrigated agriculture and cropping intensity in irrigated areas through various methods and technologies are the most viable options for achieving food security in Ethiopia. If the problem is failure of production as a result of natural causes, such as dry-spells and drought, agricultural production can be

stabilized and increased by providing irrigation and retaining more rainwater for in situ utilization by plants.

Furthermore Awulachew et al (2007) specified the challenge that Ethiopia faces in terms of food insecurity as it is associated with both inadequate food production even during good rain years (a problem related to inability to cope with growth of population) and natural failures due to erratic rainfall. Therefore, increasing arable land or attempting to increase agricultural yield by, for instance, growing higher yielding varieties of crops offers limited scope to provide food security in Ethiopia. The solution for food security will be provided by a combination of these factors, enhancing water availability for production and expansion of irrigation that can lead to security by reducing variation in harvest, as well as intensification of cropping by producing more than one crop per year. This should be combined with improved portioning, storage and soil water-retention capacity to increase plant water availability, and use of highland Ethiopia. There are also important other ways to reduce risk for farmers (social, economical, spatial diversity) and for the government (trade, buffer, pricing).

The estimate of the irrigation potential of Ethiopia vary from one source to the other, due to lack of standard or agreed criteria for estimating irrigation potential in the country. Awulachew et al (2007) used earlier reports, which showed the irrigation potential at a lowest of 1.0 and 1.5 million hectares, and a highest of 4.3 million hectares.

Similarly, there is no consistent inventory with regard to the developed irrigation of the country. As Awulachew et al (2007) stated, in 1990 the total estimated irrigated agriculture for the country is 161,000 ha as a whole, of which 64,000 ha was in small-scale schemes, 97,000 ha in medium- and large-scale schemes, and approximately 38,000 ha was under implementation. And the traditional irrigation schemes alone cover 138,339 ha, and that 48,074 ha are under modern small-scale irrigation, 61,057 ha under modern large- and medium-scale schemes, with the aggregated sum of irrigated agriculture at 247,470 ha. From the latter, it can be seen that small-scale irrigation contributes 75 percent of the irrigation-56 percent from traditional and 19 percent from modern small-scale irrigation.

Given the current household level irrigation expansion through traditional schemes and water harvesting, it is assumed that the total sum of actual irrigation development could be over 250,000 ha. One of the limiting factors of irrigation potential is water abstraction. The Ethiopian hydrographical network often shows deep and narrow gorges that make water abstraction costs extremely high. However, construction of multipurpose dams for irrigation, hydropower and flood control may help reduce the per hectare cost of development (Awulachew et al., 2007).

Ethiopia in deed has significant irrigation potential assessed from both available land and water resources potential, irrespective of the lack of accurate estimates of potentially irrigable land and developed area under irrigation. Despite efforts of the government to expand irrigation, the country has not achieved sufficient irrigated agriculture to overcome the problems of food security and extreme rural poverty, as well as to create economic dynamism in the country (Awulachew et al., 2007).

### **2.3 Irrigation development in Ethiopia**

As Dejen et al (2012), in Ethiopia, about 90% of the irrigation potential in terms of land and water resources has not been developed so far. However, there have been many ongoing medium and large-scale irrigation developments in recent years. While about 47% of the developed area is under large-scale public irrigation schemes, mainly industrial crops such as Cotton, Sugarcane and various fruits are grown. About 65% of the irrigated area is under small-scale irrigation schemes, either modern or traditional. Traditional irrigation schemes are those developed by farmers themselves and are without permanent water diversion, conveyance, and control and distribution facilities. Modern schemes are those equipped with basic irrigation infrastructure such as water diversion and flow control structures and conveyance and distribution systems. Modern small-scale schemes account for about 18% of irrigated area to date. Small-scale schemes are operated and managed by the water users themselves with little involvement of government agencies in some cases. Ministry of Water Resources emphasizes that in Ethiopia, these schemes have been playing a significant role in ensuring food security at household level and in improving the livelihood of the rural poor.

According to Adenew (2006), in smallholder agriculture, production system is largely characterized by subsistence orientation, low levels of external inputs, dependency on rainfall, and limited integration into the market. As the country has so far only developed, only a very small share of the potentially irrigable land, agricultural is vulnerable to the vagaries of nature, particularly rainfall instability and drought.

Owing to the low productivity or low production and insignificant saving, the smallholder producers are predominantly caught in the poverty trap. Lack of saving constraints capital investment in expansion and intensification of production. Hence, with low external level of input, the crop cultivation and natural resources management operates at an imbalance between nutrient input and extraction leading to soil and land degradation, with consequent declining productivity and production. The rising population pressure particularly in the highland agricultural zones has exacerbated the problem in relation to declining farm holdings and land fragmentation (Adenew, 2006).

Attempts have been made during the last many years to expand the use of modern input technologies like chemical fertilizers, improved seed, herbicides/pesticides and new

agronomic practices. Although high yields can be obtained in good soil and favorable weather conditions, the overall national average yield of major products, particularly cereals and pulses did not show much improvement. A combination of many factors including weakly functioning agricultural markets, low purchasing power of the consumers, overall low level of technical knowledge of the producers and a high illiteracy rate of the rural communities have hindered the much expected technical change and farm productivity (Adenew, 2006).

The country's agricultural sector has shown no significant structural transformation and is dominated by smallholder producers. Large-scale commercial productions run by the state were not given attention any more following the economic liberalization policy and programs of public enterprise privatization. Private commercial farms are still very limited although their role is growing (Adenew, 2006).

It is believed that Ethiopia has total volume of 123 billion cubic meters of surface water and about 2.6 billion cubic meters of groundwater. The distribution is not, however, uniform. The western half of the country receives sustainable amounts of precipitation and has many perennial rivers and streams while the precipitation is marginal in the eastern half the country (McCornick et al, 2003).

The Ministry of Water and Energy has identified 560 irrigation potential sites on the major river basins. The total irrigable land in Ethiopia is estimated to be around 3.7 million hectares (without considering the groundwater potential and gently sloping areas). The area under irrigation development to-date is estimated to range between 160,000-200,000 hectares for the entire country. Estimates of the irrigated area vary, but still is less than five percent of the potentially irrigable land. Area bigger than the current irrigated land is planned to be developed for cane production within the coming five years and considerably large area for smallholder farmers. Ethiopia has set itself an ambitious task to achieve an irrigation target of 1.8 million hectares for irrigation development. The challenges includes amongst others: closing the gaps between planning and implementation of irrigation projects; improving the performance of existing irrigation schemes; removing constraints on the scale-up irrigation projects; and ensuring the sustainability of water resources for irrigation. Non-functionality is estimated at 17-35%; low-functionality is much larger (FAO, 2011).

#### **2.4 Water resources of the Awash River Basin**

According to Taddese et al (2000), Plateaus over 2500 m receive 1400-18000 mm/yr, mid-altitude regions (600-2500 m) receive 1000-1400 mm/yr, and lowlands get less than 200 mm/yr. The rainfall distribution, especially in the highland areas is bimodal, with a short rainy season in March, April and the main rains from June to September like

Modjo, Akaki, Kessam, Kebena and Mille rivers carry water the whole year, while many lowland rivers only function during the rainy seasons.

Potential evapotranspiration (PET) in the Upper Valley at Wonji is 1810 mm over twice of the annual rainfall. At Dupti, the lower Valley the mean PET is 2348 mm, which is over ten times the average annual rainfall. Mean annual temperature range from 20.8 to 29 °C at Koka and at Dupti from 23.8 °C to 33.6 °C in June. The mean annual stream flow at Koka is 1.9 m/s and in Middle Awash Valley exceeds over 2m/s in July Taddese et al (2000).

The Koka dam (11500 km<sup>2</sup>) was commissioned in 1960, and the mean annual runoff into Koka reservoir amounts 1660 Mm<sup>3</sup>. At Awash station the annual runoff decreases to 1360 Mm<sup>3</sup> depleted largely by losses from Koka Dam by Upper Valley irrigation diversions. Total mean annual water resources of the Awash River Basin amounts to some 4900 Mm<sup>3</sup> of which some 3850 Mm<sup>3</sup> is currently utilized, the balance being largely lost to Gedebassa Swamp and elsewhere in the river system.

Taddese et al (2000) tried in putting the potential for major ground water development for irrigation in Awash River Basin with the recharge of 14-26%. In addition, the paper put the ground water flow direction in the basin is towards northeast to Lake Abe (243 m asl) and to the Denakil depression (-141 m asl). The total ground water recharge is 3800 Mm<sup>3</sup>/yr. There are numerous springs that feed the ground water with high flow variability 1000 l/s in the wet season and less than 10 l/s in the dry season; in the Uplands the depth to the ground varies from 10-250 m, from less than 5 l/s to the high yield of 15-18 l/s.

As Taddese et al (2000), a delicate hydrological balance characterizes the lower Awash River Basin where, in a normal year, inflows equal losses in lakes and wetlands. Below Dupti in Ethiopia, no appreciable runoff from local rainfall reaches the river. The available water from rainfall in the basin is 39,845 Mm<sup>3</sup>/yr, 72% of the rainfall (28383 Mm<sup>3</sup>/yr) is lost through evapotranspiration, 18% (7386 Mm<sup>3</sup>/yr) runoff and 10% (4074 Mm<sup>3</sup>/yr) is rechargeable water.

The Upper Awash Basin and its major tributaries have been subjected to major environmental stress. The demand for natural resources by the high and fast growing population remains a major challenge to effective agricultural and forestland management. The high pressure on forest resources in particular, has led to the exploitation of fragile watersheds and ecosystems that have resulted in loss of vegetation and subsequent soil erosion in the lower part of the Awash River Basin (Taddese et al., 2000).

### **2.4.1 Hydrological description of Awash River Basin**

Diagnosis and opportunities (2006) described the pivotal role of Hydrology in erosion, land degradation, reduced soil fertility and productivity, and siltation. According to it, Ethiopia's high intensity storms cause significant erosion. The erosive effects of rainfall are significantly augmented by Ethiopia's mountainous terrain, severe deforestation, and traditional agricultural practices of cultivating steep slopes without protective measures. The loss of forest cover, in turn, is generally associated with greater hydrological variability.

In addition to the above stated effects of hydrology that Diagnosis and opportunities (2006) stated, sedimentation compromises productivity and shortens the lifespan of water infrastructure for river regulation, municipal water supplies, and agriculture and hydropower generation. The reduced regulation capacity also increases flood risks for downstream communities, which poses a particular risk to the poor, who tend to live in the most vulnerable locations.

Rainfall variability is also incorporated in hydrological role as raised by Diagnosis and opportunities (2006). Ethiopia's extreme hydrological variability is echoed in its economic performance. The vast majority (80 percent) of Ethiopia's population subsists on rainfed agriculture. The impact of rainfall variability, unchecked by either physical infrastructure or strong management practices, can be felt not only on agricultural output but also on the environment, electricity (which is 90 percent hydropower), manufactured goods, incomes and consumption, and prices.

Hydrological variability costs the Ethiopian economy 38 percent of its potential growth rate and causes a 25 percent increase in poverty rates, clearly demonstrating the extraordinary impact of drought, and particularly variability, on the Ethiopian economy. A single drought event in a 12-year period-a very conservative estimate for Ethiopia-will decrease average GDP growth rates 7-10 percent. If historical levels of variability and the partial impacts of floods are incorporated, GDP growth rates fall 20-43 percent Diagnosis and opportunities (2006).

In terms of poverty, the impact of a single drought will increase poverty rates 12-14 percent, causing an additional 5 million Ethiopians to be living in poverty by the year 2015 (relative to the non-drought case), 17 million more than today. With hydrological variability, projected poverty rates raise 25-35 percent and project 51 million people living in poverty, 22 million than today. The country has adequate average annual rainfall, several major rivers, and significant groundwater resources. The total renewable surface water resources are estimated at 122 billion cubic meters per year from 12 major river basins. Renewable groundwater resources are estimated to be about 2.6 billion cubic meters Diagnosis and opportunities (2006).

Bastiaanssen and Bos (1999) stated that although less than 2 percent of these resources are diverted for use, the current estimated per capita renewable fresh water resources of 1,900 cubic meters indicates an abundant of water.

However, the development and management of Ethiopia's water resources faces two significant challenges, a natural legacy and a historical legacy. The natural legacy is one of high hydrological variability. Rainfall across much of the country is exceptionally variable and unpredictable, in both time (within and between years) and space. With highly vulnerable watersheds and almost no investment in water storage, a consequence of this hydrological variability is endemic and unpredictable drought and flood. The historical legacy is one of several international rivers Bastiaanssen and Bos (1999).

Ethiopia's hydrology is greatly influenced by its varied topography. The heart of the country is a vast highland plateau, lying at an elevation of 1,500-3,000 meters with some peaks rising to more than 4,500 meters. This central massif is divided by the deep rift valley, which runs from northeast to southeast. To the west, the plateau slopes gently away to the Sudan and to the wide plains of the White Nile and Main Nile. To the east, a steep escarpment drops to the plains of the low lands; farther south, these merge into the great stretch of the Ogaden Desert Bastiaanssen and Bos (1999).

The Ethiopian highlands contribute to three major river systems, the Nile, Awash, and Omo. The northern and the central highlands drain westward into Ethiopia's largest river system, the Abbay, or Blue Nile, into the Tekeze River, a tributary of the main Nile, and into the Baro River, a tributary of the White Nile. The eastern highlands drain into the Awash River, which never reaches the sea, but it ultimately absorbed into a succession of lakes and marshes near the Djibouti border. In the south, the Omo River drains into Lake Turkana, and a number of streams flow into the other Rift Valley lakes. In the southeast, the mountains of Arsi, Bale, and Sidamo drain toward Somalia and the Indian Ocean, but only the Genale or Juba River permanently flows into the sea. Apart from the larger rivers, there are few perennial streams below 1,000 meters Bastiaanssen and Bos (1999).

High sediment loads in rivers can reduce power generation capacity, interfere with irrigation, contribute to flood risk, and affect clean water supplies. Ethiopia's annual average sediment yield ranges between 10 tons per square kilometer (in the southwestern parts of the country) to about 1,500 tons per square kilometer (in the northern and eastern parts of the country). When sediments settle in reservoirs, the capacity for power generation is reduced in proportion to the sediment ingress into the reservoir. In addition, concentration of sediment at the power inlets has hampered operation of dam bottom outlets as well as power intakes Bastiaanssen and Bos (1999).

While the impact of flooding on the energy sector has been relatively limited, flooding has caused damage to generation equipment at the Melka Wakana and Tis Abbay power

plants. The Koka Dam-which provides the only control on the Awash River for irrigation and hydropower generation and regulates water supplies to more than 70 percent of the nation's large-scale irrigation-has lost its flood control capacity because of siltation Bastiaanssen and Bos (1999).

Available water for downstream development has sharply declined. The reduced regulation capacity has caused flood damage on farmlands in the upper and middle valleys. Irrigated agriculture is also threatened by sedimentation in the storage reservoirs and conveyance structures, which adds to the overall operating and maintenance costs. Sedimentation affects water supply to towns that rely on surface water sources as well Bastiaanssen and Bos (1999).

### **2.5 Some irrigation schemes in Awash River Basin**

The Awash basin is the most important river basin in Ethiopia, and covers a total land area of 110,000 square kilometer and serves as home to 10.5 million peoples. The Upper, Middle and Lower Valley are part of the Great Rift Valleys systems. The Lower Awash Valley is a semi-arid to arid region. In the early 50's the Koka Dam was built, which served for hydropower and irrigation development downstream. Large-scale state farms were developed since, which produced mainly cotton. The Awash Basin accounts for about half of the the national irrigation schemes (Awulachew et al, 2007).

Currently however, schemes that were operative under public enterprises are transferred either to the communities in the surrounding areas or to private developers. In most cases however, the communities themselves did not use the irrigated land. Therefore, some investors arranged with the communities and are currently operating the farms, growing mainly cotton and millet. However, large areas of irrigated land have been left fallow. The reasons behind this are; lands were claimed by different clans which resulted in conflict, and a lack of capacity at regional governments to implement and control land and water management policies. As a result, also private investors backed away from investing in the development and operation of these farms (Awulachew et al, 2007).

In addition to these a large number of new irrigation schemes have been developed on the Awash. The ongoing Tendaho Sugar Development Project with 60,000 hectares of land to be developed for cane production is the largest ever on Awash River. The Fantale and Tibila Irrigation Projects are also ongoing projects owned by the Regional Government of Oromia. It is planned to irrigate about 30,000 hectares of land for smallholder farmers and more than 5,000 hectares of land have been irrigated so far. Fantale and Tibila irrigation Projects are also unique in their implementation modality and the ownership and scheme administration arrangements.

By now the Awash River is as good as overcommitted with no scope for further development. But the construction of additional dams at Kessem and Tendaho help to

minimize the water stress that may come through the intensive use of the river water (Awulachew et al, 2007).

### **Wonji-shoa sugar estate**

The Wonji-Shoa Sugar Estate lies downstream of the Koka Dam in the Central Rift Valley of Ethiopia in the Awash River Basin, 110 km southeast of Addis Ababa and 10 km south of Nazareth. It is found at an altitude of approximately 1,500 meters above sea level. In the Estate, generally, the slope of the farm is very gentle and regular. More than 50 percent of the farm is heavy clay soil and the rest is light soil. It has a semi-arid climate and receives an average annual rainfall of 831.2 mm, peak daily evapotranspiration of 4.5 mm, mean annual maximum and minimum temperatures of 27.6 °C and 15.2 °C respectively. The total concession area of the estate is 6,162.8 ha, of which 5,905.13 ha are under cultivation, while 257 ha are occupied for canals, roads, living quarters, etc. out-growers irrigate an additional area of 1,117 ha of land.

Water is pumped from Awash River through a pumping station at Wonji and almost the entire estate is fed from this pumping station through an extensive earthen canal system and storage facilities. Pumps run continuously to store water in the reservoirs, which are spread at various locations in the estate, and the estate irrigated partly from the water supplied directly by the pumps and the rest from the reservoirs.

Blocked-end furrow irrigation system is used to irrigate sugarcane fields in the estate as well as in the farms of the out-growers. Water applied to each furrow is cutoff as it reaches the end of the furrow, which is blocked and ponds up within the furrow.

The hand feels or finger test method is used to recognize the need for irrigation (Girma and Awulacchew, 2007).

### **Metahara Sugar Estate**

Metahara Sugar Factory is located about 200 km southeast of Addis Ababa within the Upper Awash Valley. It is found at an altitude of 950 meters above sea level and has a semi-arid climatic conditioned the average annual rainfall is 543 mm. the average pan evaporation is 6.9 mm. the maximum and minimum relative humidity are 85.4 and 30.3 percent, respectively. The hottest period of the year extends from March to June whereas the coldest period extends from September to January. The soil type ranges from sands to clay loam. Most of the plains in Metahara are gentle and suitable for gravity irrigation; hence, more than 81 percent of the farm is irrigated by gravity. The enterprise currently has a total concession area of 14,733 ha, out of which about 10,300 ha is covered with sugarcane plantation. The total design area of the scheme is 10,358 ha.

Irrigation water is abstracted from the Awash River via two diversion weirs and intake head works found at Metahara and Abadir. The method of water abstraction is gravity diversion. There are 23 reservoirs for irrigation water storage, where the water holding

capacity ranges from 6500 to 93000 m<sup>3</sup>. More than 1200 km of canal network supplies irrigation water to sugarcane fields, predominantly using the gravity system with night storage reservoirs balancing out day and night irrigation flows. Water delivery infrastructure consists of unlined canals but with some lined canals in particular areas of the estate. Manual gates are used to control irrigation water. Furrow irrigation using plastic siphons are used (Girma and Awulacchew, 2007).

### **Golgota and Wedecha**

The Golgota and Wedecha schemes are located in central Ethiopia in Awash River Basin. Golgota scheme is supplied with water from the main Awash River with temporary diversions. However, at about 500 m from the temporary diversion there are sluice gates on the bank of the canal to regulate the flow. These sluices are used to release excess water from the canal bank to the river and to scour sediment entering at the head of the canal. Water is conveyed in a earthen main canal and is distributed through three main tertiary off-takes equipped with sluice gates. The nominal command area of the scheme is about 600 ha. The two sub-systems; that is, Godino and Gohaworki of the Wedecha scheme are supplied with water from Wedecha Reservoir. Water is taken through a piped outlet under the embankment dam and is conveyed via the natural river channel. At some 5 km distance from the dam, there is a diversion weir with off-takes on the right bank that supplies water to Gohaworki sub-system. At 1 km downstream of the first weir is the second diversion weir with off-takes on the left bank that supplies water to Godino sub-system. The regulating gates at both of these off-takes were demolished by farmers. Currently, flow into the canals is diverted at the off-takes with stones and wooden logs. Water is diverted into rectangular masonry lined canals at both off-takes and is distributed using poorly constructed earthen channels. The nominal command area of Godino sub-system is about 300 ha while that of Gohaworki is about 60 ha, with a combined nominal command area of 360 ha (Dejen et al., 2012).

### **2.6 Irrigation efficiency definitions**

Although in irrigated agriculture, the potential for water savings is generally large, upstream interventions do not necessarily increase the water availability for downstream users. The general solution to deal with water scarcity is the improvement of irrigation efficiency. This concept of efficiency however can be misleading, as upstream seepage losses contribute to the recharge of aquifers and losses from a project can be recovered downstream (if the water quality has not deteriorated too much) (Bastiaanssen and Bos., 1999).

Efficiency alone is not a sufficient indicator to define and improve the performance of an irrigation system. Expressing irrigation efficiency in numbers depends up on the scale. The general accepted figure for field scale irrigation efficiency is 45 %, while efficiency

regarded from the river basin as a total system (with recycling of percolation water) can be as high as 80 to 100% (Bastiaanssen and Bos., 1999).

Recycling and return flows in irrigation systems are often not properly understood, and the impact of upstream interventions on the hydrology of the surrounding environment should be considered carefully (Bos et al., 1991).

Irrigation efficiency is generally defined from three points of view: (1) the irrigation system performance, (2) the uniformity of water application, and (3) the response of the crop to irrigation. These irrigation efficiency measures are interrelated and vary on a spatial and temporal scale. The spatial scale may be defined for a single field, or on a larger scale up to a whole irrigation district or watershed. The temporal scale can vary from a single irrigation event to a longer period such as part of the growing season, or a period of years (Irmak et al, 2011).

## **2.7 Evaluating irrigation system performance**

Irrigation performance describes the effectiveness of the physical system operating decisions to deliver irrigation water from a water resource to the crop. Several efficiency terms are used to evaluate irrigation system performance FAO (1989).

### **2.7.1 Application efficiency**

Application efficiency is the most important in terms of design and management since it reflects the overall beneficial use of irrigation water. Design and management strategy will be proposed in which the value application efficiency is maximized subject to the value of requirement efficiency being maintained at 95-100 percent. This approach thereby eliminates storage efficiency from an active role in the surface irrigation design or management and simultaneously maximizes application efficiency (FAO, 1989)

After the water reaches the field supply channel, it is important to apply the water as efficiently as possible. A measure of how efficiently this is done is the application efficiency. One very common measure of on farm irrigation efficiency is application efficiency. The definition of application efficiency,  $E_a$ , has been defined as

$$E_a = \text{Depth of water added to the root zone} / \text{Depth of water applied to the field.}$$

Application efficiency is a common yardstick of relative irrigation losses and this definition is valid for all situations all irrigation methods (Jurriens et al, 2001).

Losses from the field occur as deep percolation and as field tail water or runoff and reduce the application efficiency. To compute  $E_a$  it is necessary to identify at least of these losses as well as the amount of root zone storage capacity available at the time of irrigation and the actual water stored due to irrigation be separated (FAO,1989).

Methods of determining application efficiency of a specific irrigation system is generally time consuming and often difficult because it may vary in time due to changing soil, crop and climate condition (Roger et al., 1997).

### **2.7.2 Conveyance efficiency**

Irmak et al (2011) defined conveyance efficiency as; Irrigation water is normally conveyed from a water source to the farm or field through natural drainage ways, constructed earthen or lined canals, or pipelines. Many conveyance systems have transmission losses, meaning that water delivered to the farm or field is usually less than the water diverted from the source. Water losses in the conveyance system include canal seepage, canal spills, evaporation losses from canals, and leaks in pipelines. The water conveyance efficiency is defined as the ratio between the irrigation water that reaches a farm or field to that diverted from the water source and expressed as:

$$E_c = (V_f / V_t) * 100$$

$E_c$  = water conveyance efficiency (%)

$V_f$  = volume of irrigation water that reaches the farm or field

$V_t$  = volume of irrigation water diverted from the water source

### **2.7.3 Storage efficiency**

Small irrigation may lead to high efficiencies, yet the irrigation practice may be poor. The concept of water storage efficiency is useful in evaluating this type of problem. The water storage efficiency refers how completely the water needed prior to irrigation has been stored in the root zone during irrigation. Storage efficiency is defined as (Roger et al., 1997):

$E_s$  = Volume of water added to the root zone storage / potential soil moisture storage volume

The requirement efficiency is an indicator of how well the irrigation meets its objective of refilling the root zone. The value of  $E_s$  is important when either the irrigations tend to leave major portions of the field under-irrigated or where under-irrigation is purposely practiced to use precipitation as it occurs and storage efficiency become important when water supplies are limited (FAO, 1989).

FAO (1992) specified as water stored in the root zone is not 100% effective. Evaporation losses may remain high due to the movement of soil water by capillary action towards the soil surface. Water lost from the root zone by deep percolation where groundwater is deep. Deep percolation can persist after attaining field capacity. Depending on the

weather, type of soil and time span considered, effectiveness of stored soil water might be as high as 90% or as low as 40%.

#### **2.7.4 Distribution efficiency**

According to FAO (1989), when a field with a uniform slope, soil and crop density receives steady flow at its upper end, a waterfront will advance at a monotonically decreasing rate until it reaches the end of the field.

Water lost to percolation below the root zone due to non-uniform application or over application water runoff from the field, all reduces irrigation efficiencies (Roger et al., 1997).

### **2.8 Factors affecting conveyance efficiency**

There are many factors which affect irrigation efficiencies in the literature. Few factors are described below.

#### **2.8.1 Soil salinity and water logging**

Salinity problems are recognized throughout the Lower Awash Valley. Another common problem in drained marshes and swamps is that soils become infertile and acid because of oxidation of sulphur and production of sulphuric acid in the drained soils. In poorly drained soils wilt syndrome to cotton is produced under anaerobic condition in the presence of easily oxidizable organic matter, presently hydrogen sulphide and reduction of  $\text{NO}_3$ , Fe, Zn and Cu, this affects growth of cotton root causing damage and other deformation in plants. Development of large-scale irrigation projects without functional drainage system and appropriate water management practices have led to gradual rise of saline ground water in the Middle Awash region. Because of reduced initial reservoir capacity of the Koka Reservoir, the flood holding capacity has been reduced substantially. This situation has created the problem of increased flooding risk downstream and shortage of water supply for irrigation and power generation (Taddese, 2000).

Lower Awash: The lower awash area comprises a flat plain of over 100,000 ha of this about 70,000 ha is earmarked for irrigation. Currently, flooding is caused by river Mile and Logiya. A dam at Tendaho is required for irrigation development downstream. Construction of a dam at Tendaho would absorb any flooding from Mille and Awash itself. Logiya being downstream from Tendaho dam site will continue to cause flooding. If proper river training is maintained, the Awash River channel can manage to contain any flow from Logiya river within its banks assuming that Tendaho dam is constructed. Middle Awash: flooding in this stretch of the Awash River is mainly caused by rivers Kesseme and Kebena, which are tributaries to the Awash from the western high land drainage. This may be aggravated by high flood spill from Koka Reservoir. Because of

the weakening of Amibara project control center, which is responsible for protecting the development from flooding by maintaining dikes, repeated flooding has caused substantial economic losses in the last couple of years. Upper Awash: Becho plain, located about 30 km West of Addis Ababa on the Jimma road is annually flooded during the rainy season with over flow from the Awash River. The flood covers both sides of the Addis Ababa-Jimma highway (Taddese, 2000).

Rhoades (1997) reported estimates that as much as 20 percent of the irrigated land may already be experiencing yield declines due poor drainage (water logging and salinization) caused by over-irrigation as cited by Walker (2003).

As Walker (2003), approximately 70 percent of initial fresh water withdrawals are allocated to agriculture where irrigation is the predominant agricultural use. Overall project efficiency may be as low as 40 percent. Stated in other terms, about 2.5 times the amount of water resources available for urbanization and industrialization. As the fresh water supplies come under increasing demand from these other sector, irrigated agriculture cannot be this inefficient.

Salts are contributed to the irrigation system by two main processes: salt concentration and chemical weathering. Salt concentration effects occur in the soil due to the removal of water by the consumptive use of crops and other natural vegetation. Irrigation along with the inter-basin export of high-quality water and evaporation from the water surfaces of streams and lakes are major causes of increased salinity levels caused by concentrating effects. Salts may also accumulate in the soil by the chemical weathering of the soil and substrata by irrigation water and natural sub-surface flows. Also known as “salt loading,” it contributes to the concentrations in water supplies along with excessive fertilizer applications, municipal and industrial wastes, and point sources such as mineral springs, flowing brine wells, and geysers. If the salts accumulating in the root zone because of evapotranspiration or weathering are not periodically leached from the crop root zone, the land will become unproductive. However, the water which passes through the root zone carrying the excess salts may be severely restricted from further travel by subsurface conditions. When this occurs, this leachate will eventually build up into the root zone, causing high salinity levels and poor aeration. In many areas, drainage is more than adequate, movement of salts from irrigated lands contaminates local groundwater basins, and stream flows (Walker, 2003).

### **2.8.2 Performance gaps and technological transfer**

Irrigation eventually failed in many regions of the world either because lack of the necessary knowledge for irrigation management or incapability of the available knowledge and technology to cope with the problems being created Kamara and McCormick (2012).

According to Yusuf (2004), farmers in an irrigation scheme cannot just open and close their gates. Farmers who are located closer to the source are over irrigating and the downstream users receive no water, which is the cause irrigation inefficiency.

In terms of gaps in knowledge, a significant amount of knowledge about current irrigation practices and the measures required to improve irrigation efficiency exists, but has not been well transferred to the general public practitioners in the field. The biggest gap therefore, is communicating the knowledge to stakeholders Yusuf (2004).

There are four potential kinds of performance gaps that can occur with irrigation systems (Yusuf, 2004).

The first is a technological performance gap. This is when the infrastructure of an irrigation system lacks the capacity to deliver a given hydraulic performance standard. The normal solution to technology performance gap is to change the type, design or condition of physical infrastructure.

The second kind of performance gap is when a difference arises between how management procedures are supposed to be implemented and how they are actually implemented. This includes such problems as how people adjust gates, maintain canals and report information. This can be called a gap in implementation performance. A problem of this kind generally requires changes in procedures, supervision or training.

The third kind of performance gap is a difference between management targets and actual achievements. Examples of management targets are the size of area served by irrigation in a given season, cropping intensity, irrigation efficiency, water delivery schedules and water fee collection rates. This can be called a gap in achievement. Such problems are generally addressed either by changing the objectives (especially simplifying them) or increasing the capacity of management to achieve them such as through increasing the resources available or reforming organizations.

The fourth type of performance problem concerns impacts of management. This is a difference between what people think should be the ultimate effects of irrigation and what actually results. These are gaps in impact performance and include such measures as agricultural and economic profitability of irrigated agriculture, productivity per unit of water, poverty alleviation and environmental problems such as water logging and salinity. If management procedures are followed and targets are being achieved, but ultimate impacts are not as intended, the the problem is not that the managing organization has performed badly, since the effects are generally beyond its direct control. The problem is that the objectives of the organization do not produce the desired impacts. This is more a problem of policy than management.

Furthermore, Tom et al (1999) has discussed on irrigation efficiencies and identified some of the causes of irrigation inefficiencies as follow:

Inefficient use of water – a precious Resource: Sub-optimal use of limited surface water run-off being channeled into small-scale irrigation schemes was observed on numerous occasions within the series of sites visited. There were two reasons for this inefficient use of water:

- ➡ Leakage from unlined canals or from breakages in the canal system; and
- ➡ Faulty use of irrigation water (over-watering in flood irrigation regimes).

### **2.8.3. Effects of hydraulic parameters on conveyance efficiency**

Many studies point out that in the canal irrigation system there is inadequate distribution of water, lack of proper and timely regulation of water, poor repair and maintenance of irrigation channels, inefficient use of water, water logging and salinity problems Catterson (1999). According to Horst et la (2005) cited by Catterson (1999) the causes for low application efficiency were very high advance time, short intervals between irrigations, and excess water application related to extended cut-off times. Moreover, Catterson (1999) specified as the most cause irrigation inefficiency as canal blockage because of sediment build-up and grass invasion.

System variables, those physical quantities whose magnitude can be varied, within a relatively wide band, by the Decision Maker (furrow length and width, unit inlet flow rate, cut off criteria) and system parameters (net irrigation requirement, hydraulic roufiness coefficient, bed slope and infiltration parameters) are the major factors affecting the irrigation efficiency There are wide variations in hydraulic, physical and chemical properties of soil in different slope segments, requiring different irrigation for different soil types. However, uniform application of water across different soil units cause over supply in areas needing less and under irrigation in areas needing more water, resulting in low irrigation efficiency and environmental degradation (Muya et al.,2001).

### **2.8.4. Hydrological effect on conveyance efficiency**

The quantity, quality, and temporal distribution characteristics of the source of irrigation water have a significant bearing on the irrigation efficiency. Crop water demands are essentially continuous during the growing season, although varied in magnitude. A small, readily available water supply is best utilized in small capacity irrigation system, which incorporates frequent application. The depths applied per irrigation are therefore small in comparison to systems having a large discharge available less frequently Walker (2003).

Water sources for irrigation are often not accurately known because of the different problems such as inaccurate or no water measurement device at source of supply, no

continuous recording of flows that vary with time, undocumented or poorly documented splitting of flows in irrigation canals, poor record keeping, inadequate rain fall records, and inaccurate separation of rain fall from irrigation water (Burt et al.,1997).

It is difficult to give general guidelines on the water requirements of irrigated crops, since they vary significantly between localities, and for specific conditions. For example, heavy soils hold more water than light soils, so that the amount of water to be applied per irrigation and the interval between irrigations is different. Water consumption by a crop depends on its stage of growth; it is greatest when an actively growing plant canopy complete shades the ground surface, maximizing interception of solar radiation (Burt et al.,1997).

#### **2.8.5. Agronomy effect on conveyance efficiency**

Farm size can affect distribution efficiency in which small size farm(less than 3 ha) has greater distribution efficiency than large farm (greater than 10 ha) because of the possibility of adjusting irrigation intervals in short period for smaller farm (Bos and Nugteren, 1990).

Scheduling irrigation is more often determined by cultural operations rather than the cultural operations being scheduled by the need for irrigation. Stand establishment, weed control, maintenance of crop vigor, control of disease, and seedbed preparation are agronomic considerations that impact irrigation system performance and need to be considered in an evaluation (JMLord and James, 2000).

### **2.9. Discharge measuring structures**

There are so many structures used to measure discharge in the literature. The descriptions of following structures are taken from Garg (2005).

#### **2.9.1. Notches**

Notches or gauge plates are constructed from thick metal plates, and used in laboratory and to measure small streams in the field. Notches have triangular (v) and rectangular types.

#### **2.9.2. Concrete or Masonry weirs**

The weirs should be used for measuring discharges with head less than 0.066 m and 0.3 m of the minimum length of the weir in open channels. The discharge values obtained by weir measurements vary from 95%- 105% of the true discharges.

### **2.9.3. Control Meters or standing wave flumes**

A control meter is a structure, which is constructed across a stream; by which critical depth can be produced by changing a subcritical channel flow into super critical flow, and vice versa. The throat is produced either in rectangular or trapezoidal in which the floor of the throat produced is level.

### **2.9.4. Parshall flume**

Par shall flume a type of constricted standing wave flume widely used for discharge measurement.

### **2.9.5. Current meters**

A current meter is the best instrument for measuring the velocity of a natural stream, and generally and universally adopted for this purpose.

### **3. Methodology**

There are several publications describing the equipment and procedures for evaluating irrigation efficiencies, but not all give a very correct methodology for interpreting the data once collected. The data analysis depends somewhat on the data collected and the information to be derived. Many performance measures existing in the literature to evaluate irrigation efficiencies, conveyance efficiency was used in this study.

#### **3.1. General description of the study area**

In order to evaluate irrigation efficiencies, two irrigation schemes Fantale and Tibila in Awash River Basin were selected. The selection criteria for selecting the two schemes were the availability of the secondary data, recommendation from the projects client and the accessibility to the sites.

##### **3.1.1 The Awash River Basin**

The Awash River basin originates from the Ginchi watershed in the central highlands of Ethiopia and flows toward Djibouti with a total length of 1200 km as outlined in the introduction part. The basin is divided into upper, middle valley and lower plains. It covers a total area of 110,000 km<sup>2</sup> of which 64,000 km<sup>2</sup> form the western catchment that drains to the main or to its tributaries. The remaining area, most of it comprises the eastern catchments, drain in to a desert area and do not contribute to the main river flow (McCornick, 2003).

A number of tributary rivers draining the highlands eastwards can increase the water level of the Awash River in a short period especially during August and September and cause flooding in the low lying alluvial plains along the river course. Tributaries to Awash river such as Kesseme, Kebena, Hawadi, Ataye jara, Mille and Logiya rivers contributed most to the lowland flooding in Afar (McCornick, 2003).

Furthermore, McCornick (2003) estimated an irrigation potential of the Awash River Basin as 206,000 ha. According to this author, 42.7% (88,000 ha) is developed so far and out of these 26.5% (23,306 ha) is under traditional and modern small-scale irrigation. State farms and private investors developed the remaining coverage. Moreover, the author divided the Basin into four zones depending on physical and climatological characteristics as Upper Basin, Upper Valley, Middle Valley and Lower Valley.

##### **3.1.2 Fantale irrigation project**

Fantale is found at a distance of 200 km Finfine / Addis Ababa and 100 km from Adama town on Asphalt road. Part of the project area located in Boset Woreda (Kawa and Huluko) is located 40-45 km off the asphalt road to east of Metehara town. Generally, both woredas are low land agro-ecological zone characterized by low annual precipitation and high temperature and geographically in the main rift-valley system in east Showa zone.

The dominant command area is situated west of Metehara town and it is bound to the foot slopes of mount Fentale on the north, Lake Beseka on the east, Rift valley escarpment on the west and rocky land (young lava flow) on the south. More precisely it falls in between 80 50' and 90 04' N latitude and 390 41' and 390 52' E longitude. The study has covered gross area of about 27,000 hectares with altitude ranging from 970 to 1020 m above sea level.

### **Topography and project boundary**

The total area covered was about 27,000 hectares out of which areas for the expansion of Metehara Sugar Factory (MSF) covered 11,000 hectares.

The project area covers Kawa and Huluko from Boset district; and Gidara, Turo Bedenota and Tututi kebeles from Fentale district.

### **Accessibility**

The Addis Ababa – Harar asphalt road, which passes through the project area and through the nearest major town, Metehara, provides the main access to the project area. The project area is also accessed by the Addis Ababa to Djibouti railway line. The all-weather road to Sabober hill in the northeast of the project area and a rough road to Berehet in the northwest of the project area provide additional access to the interiors of the project area. Both roads branch out from the main asphalt road at a point very near to the intersection of the asphalt road and railway line, within the project area. Owing to the flat topography and scattered trees, almost all parts of the project area are accessible.

The diversion site on Awash River and the Kawa command area can be accessed via Metehara Sugar Factory (MSF) 25 km on all-weather road and 5 km dry weather access road.

The mean monthly minimum and maximum temperature in the project area varies from 10<sup>0</sup>C to 38.3<sup>0</sup>C respectively. The mean minimum temperature was recorded in December and the maximum was recorded in May. May and June are the hottest months of the year.

Annual rainfall in the project area is about 500 mm. Mean monthly rainfall varies from 4.8 mm to 124 mm. The highest rainfall occurs in July and August while the lowest rainfall occurs in December. Mean monthly relative humidity of this project varies from 32% to 49%.

### **The command area**

The Command areas of the project are scattered along the main canal and divided as south and north blocks. Hence, the areas that establish under south block are Kawa, Huluko, Burka-direseden, Bomisa, Ammuma and South Illala. Similarly under North block are North Illala, Alaka, Gelcha and Haro-arba. Consequently, the areas that mentioned on the first block are found between headwork and asphalt Road/ Highway

Djibouti to Addis Ababa. And the area of the second Block are lay under Mountain Sebebor and Fentale including the area that located between the highway and Railway and beyond Railway both right and left side of the main and Branch canals. Therefore, in all Command areas irrigation water through whole canal system can flow by gravity except Kawa command area, which is irrigated by pump.

### **Agronomy study**

Different crops were grown on the command area of the project depending on climate condition of the project area, soil condition of the study area, adaptation of crops to the growing conditions of the study area, socio-economic condition of the study area and yield potential and market potentials of crops. Among, Maize, Sorghum, Onion, Pepper, Tomato, Cabbage, Groundnut, Sugarcane, Cotton, Mango, Citrus, Banana etc were crops grown on the command area during the study.

The total command area was divided in to ten (10) independent blocks/ farms. Except the major conveyance canal, all the project distribution systems were subsurface pipes.

### **Water resource and abstraction**

The water source for the whole command area of the project is the Awash River. Irrigation water for abstraction is raised by weir at the headwork of the project and conveyed through Conveyance main canal of 49.3 km and two Branch Canal 38 & 31 km with pertinent structures and Pump including Electro-mechanical equipment for Kawa command area.



Figure 3. 1 Pump station for Kawa command area

### **3.1.3 Tibila irrigation project**

It is situated approximately 155 km southeast of Finfinne, about 55 km from Adama town, about 15 km southwest of the Nura-era Estate farm and bounded in the North and North West by Awash River, in the south by Aseko district, in the north east by the Merti estate farm and in the west by the Hills of Merti district. The elevation of Tibila is lower than 1230 m above sea level. It is located at the latitude  $39^{\circ} 43' 54.1''$ E and longitude  $8^{\circ} 34' 14.8''$

#### **Accessibility**

The area can be reached from the road to Addis-Harar via Adama-Sodere-Doni or via Adama-Metehara-Nura-era; the first option is the shortest and best option to access the project area. Sodere-Doni-Metehara road is sufficiently motor-able in all seasons and crossing the entire project area. Doni-Tibila road is also motor-able in both dry and rainy seasons, and crossing the west end of the project area.

The project area has a cross sectional length of about 27 km in the east west direction and from 3 to 9 km in the north south direction. The altitude is varying from 1360 m.asl in the southern periphery to 1120 m.asl in eastern part where it is bordered by Merti estate farm.

The mean monthly minimum and maximum temperature in the project area varies from 9 °C to 25 °C respectively. The mean minimum temperature is recorded in December and the maximum is recorded in May. May and June are the hottest months of the year.

Annual rainfall in the project area is about 670 mm. Mean monthly rainfall varies from 5 mm to 172 mm. The highest rainfall occurs in August; while the lowest rainfall occurs in December. Mean monthly relative humidity varies from 30% to 49%.

Average maximum annual rainfall for the area is about 609 mm/yr while the annual minimum is 355 mm/yr. The maximum temperature ranges between 22 and 25 °C and the minimum temperature are never below 10 °C.

### **Command area**

Tibila command area was divided into 10 Blocks. The Block boundaries were fixed from suitability points of view of natural drain outlet of excess water from irrigation system and rain fall to the natural drainage ways located between two blocks. This consideration was practical for all 8 Blocks except for Block VI and VII that they do not have natural drainage way in between them.

### **Water resources and abstraction**

The project is used to take irrigation water from Awash River. Diversion weir was constructed from local materials around the site across the river at geographic coordinate of 557898 E longitudes & 936473 N latitude and an average altitude of about 1291.61 m.



Figure 3.2 Weir site for Tibila irrigation project

The main watercourses that govern the drainage nature of the study area are represented by Wererso, Mesenabo and Biskelo major Rivers and affected by Ferda, Buge and other secondary rivers and minor streams. They all are right side tributaries of Awash.

The Wererso has an angular flat terrain structure with varies size of meanders. Beskelo River - moderately deep, showing strong erosion along sides and two minor watercourses were seen between Biskelo and Wererso rivers.

To the northeast periphery of the project area, Mesenabo River is the major one. It is also moderately deep with meanders of different size and joined by two secondary Rivers namely; Laga Buge and Laga Ferda and other small stream that collect rainwater from the neighboring high land.

#### Topography

The upper reaches of the river are steep and mountainous, while the lower basin is flat with broad valley.

## **3.2 Methods used**

Data collection and analysis are presented as follows.

### **3.2.1 Data collection methods**

The data collection has started in February 2013. The first activity done was the reconnaissance survey in order to get the general insight of irrigation projects in the basin. During that Water Use Associations (WUAs), Professional staffs and some farmers were consulted about water use practices, highlight of the status of the projects and inefficiencies encountered by different projects. Based on the information gathered, the interest of the Research Team of the Ministry of Water Resources and Energy, which facilitated the transport facilities, the survey made, availability of the organizational set up of the projects and the accessibility of the roads to the projects, two large-scale irrigation projects were selected. The data collected included information gathered by discussions with respected bodies in addition to the primary and secondary data. The information gathered especially during the reconnaissance survey helped the researcher to limit collecting only the required data and directed where and when required data must be collected.

#### **3.2.1.1 Primary data collection**

The primary field data collection activities were described as follows: Frequent field observation at Fantale and Tibila projects were made to judge places where canal discharge measurement must be taken. After that, main canal discharge at carefully selected points of the two projects was taken by using the Current Meter in collaboration with the Hydrology Department of the Ministry of Water Resources and Energy. With this Current meter, canal discharge was measured at different depths across the width of the canal. The discharge measured by this equipment was obtained by dividing the number of clicks by the duration in which the number of clicks was counted. The duration in which the number of clicks counted taken was greater than forty (40) seconds in order to get high precision in measurement. The points of measurement taken were at street reaches of the canals.



Figure 3.3 Main canal discharge measurement at Fantale irrigation project

### **3.2.1.2 Secondary data collection**

Secondary data that used for this research were collected as much as possible from responsible bodies and officials. These data include discharge of the Awash River, climatic data, and existed irrigation water demand for downstream for the two projects. Discharge data collected from Ministry of Water Resources and Energy department of Hydrology contained different stations on Awash River. Stream flow gauging stations on the Awash River at Nura-era and Metahara were selected for the two projects.

### **3.3 Data analysis techniques**

In this section, conveyance efficiency evaluation and factors affecting conveyance efficiency (hydraulic and hydrologic) were presented.

#### **3.3.1 Evaluating Conveyance efficiency**

As Irmak et al (2011) defined conveyance efficiency; irrigation water is normally conveyed from a water source to the farm or field through natural drainage ways, constructed earthen or lined canals, or pipelines. Many conveyance systems have transmission losses, meaning that water delivered to the farm or field is usually less than the water diverted from the source. Water losses in the conveyance system include canal

seepage, canal spills, evaporation losses from canals, and leaks in pipelines. The water conveyance efficiency is defined as the ratio between the irrigation water that reaches a farm or field to that diverted from the water source and expressed as:

$$E_c = (V_f/V_t)*100$$

$E_c$  = water conveyance efficiency (%)

$V_f$  = volume of irrigation water that reaches the farm or field

$V_t$  = volume of irrigation water diverted from the water source

Discharge was measured at different locations over the length of the canal in order to calculate the  $E_{ci}$  at different sections.

The overall conveyance efficiency of the main canal is the product of  $E_{ci}$  calculated at different sections over the length of the canal.

Many factors affect the conveyance efficiency of an irrigation scheme. Among, hydraulic and hydrologic effects were presented in this study.

### 3.3.2 Hydraulic factors on conveyance efficiency

Many hydraulic parameters are related with irrigation efficiency. However, it is very difficult to analyse their effects considering them simultaneously. Therefore, this study used the conveyance characteristics to see the hydraulic factors on these projects. In using the Manning's formula to analyze the effects of hydraulic on conveyance efficiency; the actual value of Manning's roughness coefficient, wetted perimeter and bed slope were compared with the designed values.

$$Q = \frac{1}{n} * AR^{2/3} S^{1/2}$$

$$n = (R^{2/3} AS^{1/2})/Q$$

Where,

$Q$  = discharge of the channel ( $m^3/s$ )

$R = (A/p)$  = Hydraulic radius (m)

$A$  = Wetted cross-sectional area ( $m^2$ )

$s$  = bed slope (-)

$n$  = Manning's roughness coefficient (-)

### **3.3.3 Hydrologic factors on conveyance efficiency**

In evaluating the hydrologic effects, the design discharge for the individual projects was compared with the 70% and 80% probability of the river flow. This is whether the design discharge is greater than or less than the crop water requirement (CWR). CWR of each project was taken from the respected Irrigation agronomy study design documents.

The irrigation water requirement and the cropping pattern used were computed using the climatic characteristics generated from the Metahara weather station around the projects area. The estimation of crop water requirement underlies effective planning of crop production at farm level.

#### **3.3.3.1 Dependability analysis**

The water availability and dependability for the projects have been worked out based on hydrological data. Stream flow gauging station on the Awash River at Nura-era and Metahara were used. Eighty and seventy percent dependable flow of the river was compared with the projects irrigation water demand allowing the minimum consideration for the downstream release for environmental preservation consideration.

#### **3.3.3.2 Water Availability Analysis**

The methodology used to determine water availability in the projects area was by analyzing the Nura-era and Metahara hydrological gauging stations. Water balance of the projects is based on inflow and outflow characteristics.

The hydrological characteristic of the areas was described by the Awash River, which was draining the areas. The river originates around Arera-kore ridge located at West of Ginchi town. Among the gauging stations over the river, Nura-era and Metahara gauging stations were representative due to consistency of data and closeness of the stations to these schemes. Irrigation abstraction for the projects is coming from the downstream water release from the Koka reservoir and additional stream flow contribution of the downstream catchment during rainy season. Climatic and geologic factors control the flow availability of the river. Important climatic elements are solar radiation, temperature, humidity, evaporation, soil moisture, and vegetative growth, which subsequently affect the run off.

For Fantale irrigation project, the diversion weir is located just downstream of the gauging station. The catchment area at this location is estimated to about 14,959 km<sup>2</sup>. The Awash River catchment at Nura-era station is 14,173 km<sup>2</sup>. Out of the estimated dependable monthly flows, the least minimum flow of the month is released for downstream users and environmental purposes. As observation made during field visit and information gathered by discussion, the downstream catchment contributes less runoff due to less amount of rainfall and less vegetation cover than the upper catchment.

Terms used in flow availability analysis expression expressed below are defined as follows:

**Demand (R<sub>t</sub>):** Demand is the volume of water in Mm<sup>3</sup> required by crops for evapotranspiration and secondary needs such as requirement for leaching.

**Inflow (F<sub>t</sub>):** It is the volume of water in Mm<sup>3</sup> which is available in the river.

**Early demand (K<sub>t-1</sub>):** It is the demand of water in the volume (Mm<sup>3</sup>) for early existed schemes and other purposes.

**Flow balance (K<sub>t</sub>):** It is the volume of water in Mm<sup>3</sup> in deficit or excess of the sum of current demand and early demand minus inflow

The flow availability analysis or the flow balance is expressed as:

$$K_t = R_t - F_t + K_{t-1}$$

Where: R<sub>t</sub> = Demand in Mm<sup>3</sup>,

F<sub>t</sub> = Inflow in Mm<sup>3</sup>,

K<sub>t-1</sub> = Early demand in Mm<sup>3</sup>, and

K<sub>t</sub> = Flow balance in Mm<sup>3</sup>.

Remark: If K<sub>t</sub> is negative, storage is not required (surplus)

If K<sub>t</sub> is positive, storage is required (deficit).

#### **4. Results and discussions**

In this section, results and discussion obtained from the analysis of different data collected are presented for the two schemes.

##### **4.1 Fantale scheme**

###### **Water Resource**

Awash, one of the largest and relatively highly exploited rivers of the country is the source of irrigation water for Fantale Irrigation based Integrated Development Project.

##### **4.1.1 Conveyance efficiency of the main canal**

###### **General description of the main canal**

This section deals with the analysis of conveyance efficiency of major canal from head to tail. Fantale was designed and constructed to take maximum of 18 m<sup>3</sup>/sec of water from the river by Diversion Weir about 4 km upstream of Bole-district. The diverted irrigation water is conveyed through the Main Canal of total length about 49.3 km. At 34.650 km a Branch Canal (BC -I) is bifurcates towards the Haro-arbo area and the other Branch Canal-II (BC-II) going towards Galcha (North Block) after 49.3 km .The designed discharge of branch Canal-I and Branch canal-II were 6.72 m<sup>3</sup>/sec and 6.0 m<sup>3</sup>/sec respectively. With the allotted discharge of 18 m<sup>3</sup>/sec about 16,000 hectares of the command areas located in Fantale and Boset Woredas of east Shoa zone can be irrigated. Nevertheless, while the research carried out, the discharge released from the weir was 4.513 m<sup>3</sup>/s and the total command area developed was estimated to 8000 ha.

Irrigation water from Awash River was conveyed and distributed to the farms through a network of canals and pipes by gravity for all of the command areas except Kawa. The major conveyance systems were summarized in table 6.1 below.

Table 4. 1 Chainage for Fantale main canal

Item no.	Canal name	Chainage (km)	
		From	To
1	Main canal before Asphalt road	0+000	42+740
2	Main canal after Asphalt road	42+740	49+300
3	Branch canal-1	0+000	17+758
4	Branch canal-2	0+000	31+857
5	Branch canal-2-1	0+000	17+325

### **Geology of main canal before asphalt road (42.7 km)**

The Geological formation of the canal route of 43 km investigation was made by field observation on the soil trench excavated during the construction of the project and compared with table 6.10 (Material description along the main canal line at Fantale) obtained from agronomy report of the project design. The geology and soil conditions of the area vary in a short distance, significantly due to variability in mode of eruption of volcanic events at different levels of topography.

### **Geology of main canal after asphalt road**

The geology and soil conditions of this part of the main canal stretch has similarity with the stretch upstream of the asphalt road, where the geology vary in a short distance, significantly due to variability in mode of eruption of volcanic events at different levels of topography.

### **Discharge capacity of the main canal**

The main canal off taking from the diversion weir and serving the command areas was designed and constructed for 24-hour continuous flow. The total length covers 49.3 km.

For the purpose of accessibility and canal capacity, the canal up to Asphalt road has been divided in to three reaches:

- ◆ From the head regulator to about 17.52 Km in Gidara Peasant Association
- ◆ From 17.52 Km to 26.9 km at Bomisa
- ◆ From 26.9 km to 42.7 km Asphalt Road at Ilala and the last reach is from 42.7 km to 49.3 km up to division box to Alaka and Gelcha command areas.

The designed canal discharge capacity varies within the canal stretch, 18 m<sup>3</sup>/sec, 17 m<sup>3</sup>/sec, 15 m<sup>3</sup>/sec and 7.2 m<sup>3</sup>/sec for different sections within 49.3 km to covey sufficient irrigation water to the command areas located in both south and north farms of the project. However, the discharge measured at these sections during the research were 4.351 m<sup>3</sup>/sec, 3.353 m<sup>3</sup>/sec, 1.237 m<sup>3</sup>/sec and 0.553 m<sup>3</sup>/sec respectively.

### **Type and shape of the canal section before the asphalt road**

In areas covered by soil units, the canal constructed differ in sections, trapezoidal shaped with side slope of 1.5 H x 1 V and 1.0 H x 1.0 V (short distance for stretch covered by sound rock difficult to excavate) was adopted. On canal stretches of permeable soil formation, geo-membrane lining with a protection of boulders covered with geo-mesh was adopted.

### **Discharge capacity of the canal after the asphalt road**

Main Canal after the Addis Ababa – Djibouti road is about 6.5 km, constructed to convey irrigation water for North Ilala, Alaka and Gelcha Command areas. Discharge capacity is 7.2 m<sup>3</sup>/sec irrigation water for these command areas in full-developed command areas. However, 0.553 m<sup>3</sup>/sec was released and available during the research.

### **Type and shape of the canal section after the asphalt road**

The hydraulic canal constructed was trapezoidal with side slope of 1.5 H x 1 V. For stretches covered by sound rocks difficult to excavate, the canal shape remained rectangular section with bed clay lining. The particularity of this part of the canal is that, it was constructed to serve as storage by widening the canal section and providing head regulating weir at the end. Canal stretches of permeable soil formation, geo-membrane lining with a protection of boulders covered with geo-mesh was adopted.

### **Conveyance efficiency of the main canal**

The conveyance efficiency of the main canal is 0.77 \* 0.447 which 0.344. Conveyance efficiency of 0.77 is the efficiency before the asphalt road 42.7 km from the downstream of the weir which is obtained dividing 3.353 m<sup>3</sup>/s by 4.351 m<sup>3</sup>/s while conveyance efficiency of 0.447 is the efficiency from the asphalt road to tail of the canal which is obtained dividing 0.553 m<sup>3</sup>/s by 1.237 m<sup>3</sup>/s.

The decrease in efficiency more in the main canal after the asphalt road was due to high silt deposition and growing grass and wedding. Maintenance was started during the research was in progress but nothing reclamation and maintenance was done before.

#### 4.1.2 Hydraulic factors on the conveyance efficiency of the main canal

Hydraulic parameters change has a great effect on the conveyance efficiency of the canals. In this study, the hydraulic effect on conveyance efficiency change (decrease) was manipulated on the change on the manning's roughness coefficient (**n**). The values of the calculated **n** for different sections on the main canal were between 0.0226-0.0637. However, the designed values range from 0.017-0.03 for the same canal on which **n** was calculated. The value is increased. The increase in the value affects the amount of discharge (made to decrease) due to the canal material(s) change(s).

Table 4. 2 Comparison of calculated and designed value for n for Fantale

Canal section	Bed slope	Bed width (m)	Water depth (m)	Side slope	Area (m <sup>2</sup> )	Wetted perimeter (m)	Hydraulic Radius (m)	Flow discharge (m <sup>3</sup> /s)	Roughness coefficient <b>n</b> calculated	Designed roughness coefficient <b>n</b>
From the head regulator to about 17.525 Km	0.0012	9	0.733	1.5	7.408	11.64	0.636	4.351	0.0436	0.02
From 17.525 Km to 26.9 km	0.001	9.9	0.7859	1.5	8.707	12.73	0.683	3.353	0.0637	0.03
From 26.9 km to 42.7 km	0.001	13	0.306	1.5	4.12	14.10	0.29	1.237	0.046	0.02
From 42.7 km to 49.3 km	0.001	8.4	0.167	1.5	1.445	9.00	0.16	0.533	0.0226	0.017

Designed canal dimensions are presented on table 4.7 (Increased surface area and manning's roughness coefficient of main canal at Fantale) for more comparison with the existing dimensions.

### 4.1.3 Hydrologic factors on the conveyance efficiency of the main canal

#### *River Flows 80% Dependable*

For Awash the 80% dependable flow has been calculated for key station 2017 (Nura-era station), which is upstream of the diversion site. The 80% dependable flows for this station is shown in table 4.3 below.

Table 4.3 80% dependable mean river flow (m<sup>3</sup>/sec) of Fantale

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nura-era	27.53	27.55	27.97	29.70	26.62	27.98	39.16	55.18	57.37	35.40	24.16	25.37
Diversion site	29.06	29.07	29.52	31.34	28.10	29.53	41.33	58.24	60.55	37.36	25.50	26.77

The volume of the mean monthly 80% dependable flow of the river upstream of the diversion weir was calculated in Mm<sup>3</sup> in order to inspect excess water availability for the project demand.

Table 4.4 Estimated mean monthly 80% dependable flows of Awash River at Diversion site (Mm<sup>3</sup>) for Fantale

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Flow	77.73	70.28	79.05	81.24	75.24	76.55	110.7	156.1	156.8	100.4	66.09	71.69	1121.87

Table 4. 5 Monthly available flow and flow balance analysis

Month	Inflow (Mm <sup>3</sup> ) at G.st. Mean	Inflow at G.st. Site (80%) Dep. flow)	Inflow (mean) at diversion (Mm <sup>3</sup> )	Inflow at Diversion Site (80%) Dep. flow) (Mm <sup>3</sup> )	Irrigation Demand (Mm <sup>3</sup> )				Downstream Release (Mm <sup>3</sup> )	Flow Balance (Mm <sup>3</sup> )	Flow Balance (m <sup>3</sup> /sec)
					Downstream water users						
					Nura-era	Marti-jaju	MSF	Middle Awash Gravity			
Jan	94.807	73.652	100.064	77.736	7.780	2.713	20.443	0	6.600	40.200	15.01
Feb	83.743	66.595	88.387	70.288	7.606	2.936	24.235	0	6.600	28.911	11.95
Mar	94.405	74.902	99.640	79.056	7.706	3.188	18.981	0	6.600	42.581	15.90
Apr	91.921	76.973	97.018	81.242	7.801	3.978	21.421	13.44	6.600	28.002	10.80
May	99.947	71.295	105.489	75.249	8.705	4.979	27.664	18.42	6.600	8.881	3.32
Jun	103.626	72.528	109.373	76.551	8.315	3.373	27.769	18.74	6.600	11.754	4.53
Jul	157.387	104.872	166.115	110.688	7.490	1.325	20.490	10.734	6.600	64.049	23.91
Aug	202.787	147.895	214.034	156.097	7.688	2.605	4.796	22.334	6.600	112.074	41.84
Sep	251.460	148.580	265.405	156.820	9.830	3.71	30.013	17.038	6.600	89.629	34.58
Oct	130.474	95.097	137.709	100.371	8.043	2.744	26.906	11.367	6.600	44.711	16.69
Nov	102.645	62.621	108.338	66.094	7.386	2.73	23.171	8.853	6.600	17.354	6.70
Dec	106.574	67.928	112.484	71.695	7.369	2.783	24.615	3.308	6.600	27.020	10.09
Annual	1519.774	1226.138	1604.057	1121.887	95.719	37.064	270.504	124.234	79.2	515.166	16.34

Table 4. 6 Monthly Available flow, water demand & flow balance analysis

Month	Monthly Flow, I 80% (Mm <sup>3</sup> )	Monthly Flow, I 70% (Mm <sup>3</sup> )	Demand in Mm <sup>3</sup>					Downstream release (Mm <sup>3</sup> )	Total Demand, D (Mm <sup>3</sup> )	Flow balance, 80% Kt (Mm <sup>3</sup> )	Flow balance, 70% Kt (Mm <sup>3</sup> )	Remark
			Fentale	Marti Jaju	Nura Era	MSF	Middle Awash					
Jan	77.736	83.673	13.239	2.713	7.780	20.443	0	6.600	50.775	-26.961	-32.898	Surplus
Feb	70.288	75.106	10.313	2.936	7.606	24.235	0	6.600	51.690	-18.598	-23.416	Surplus
Mar	79.056	85.573	6.025	3.188	7.706	18.981	0	6.600	42.500	-36.556	-43.072	Surplus
Apr	81.242	86.208	10.261	3.978	7.801	21.421	13.44	6.600	63.501	-17.741	-22.707	Surplus
May	75.249	81.703	14.998	4.979	8.705	27.664	18.42	6.600	81.366	6.117	-0.337	Surplus
Jun	76.551	84.963	15.132	3.373	8.315	27.769	18.74	6.600	79.929	3.378	-5.034	Surplus
Jul	110.688	123.695	16.726	1.325	7.490	20.490	10.734	6.600	63.365	-47.323	-60.330	Surplus
Aug	156.097	170.208	26.076	2.605	7.688	4.796	22.334	6.600	70.099	-85.998	-100.109	Surplus
Sep	156.820	188.116	41.147	3.71	9.830	30.013	17.038	6.600	108.338	-48.482	-79.778	Surplus
Oct	100.371	110.122	25.340	2.744	8.043	26.906	11.367	6.600	81.000	-19.371	-29.122	Surplus
Nov	66.094	76.507	14.019	2.73	7.386	23.171	8.853	6.600	62.759	-3.335	-13.748	Surplus
Dec	71.695	82.394	14.105	2.783	7.369	24.615	3.308	6.600	58.780	-12.915	-23.614	Surplus

**Remark: Irrigation demand of Fentale command was taken from Agronomy report for 24 hrs supply**

For 80% dependability irrigation requirement for Fentale cannot be meet in the month of May & June, but it will meet the requirement 70% dependability.

$$K_t = D - I,$$

Since it could not get 10 days data of water demand from Marti-jaju, Nura-era, MSF, Middle Awash and Awash Basin Authority, monthly basis data for water balance analysis was used.

#### 4.1.3.1 Evaporation loss from the canal at Fantale

Table 4.7 Increased surface area and manning's roughness coefficient of main canal at Fantale

Canal section	Bed slope designed	Bed slope measured	Bed width (m)	Water depth (m) designed	Water depth (m) calculated	Side slope	Flow discharge (m <sup>3</sup> /s) designed	Manning's roughness coefficient <b>n</b> Designed	Manning's Roughness coefficient <b>n</b> calculated	A (m <sup>2</sup> ) designed	A (m <sup>2</sup> ) Cal.	Sur.A inc. (m <sup>2</sup> )
From head regulator to 17.525 Km	0.001	0.0012	9	1.13	1.61	1.5	18	0.02	0.0436	12.08	18.51	0.3456
From 17.525 to 26.9 km	0.0012	0.001	9.9	1.22	1.88	1.5	17	0.03	0.0637	14.31	23.9136	0.6534
From 26.9 to 42.7 km	0.001	0.001	13	0.86	1.31	1.5	15	0.02	0.046	12.24	19.60	0.3078
From 42.7 to 49.3 km	0.0008	0.001	8.4	0.69	0.82	1.5	7.2	0.017	0.0226	6.51	7.90	0.02535

Evaporation loss from increased area of the canal is calculated using Energy balance method as:

$$E = \frac{1000}{l_v w} (R_n - H_s - G)$$

Where: E is evaporation in l/s

$l_v$  is latent heat of vaporization in KJ/kg

$R_n$  is net radiation flux in W/m<sup>2</sup>

Hs sensible heat flux in KJ/kg

G ground heat flux in KJ/kg

w is density of water in Kg/m<sup>3</sup>

Assuming Hs and G being zero and  $R_n = 200 \text{ W/m}^2$ ,  $l_v = 2500 - 2.36 * T^{\circ}\text{C}$ , Evaporation from open increased canal surface is (Chow et al., 1988) summarized in table 4.8 below.

Table 4.8 Evaporation (l/s) loss from increased canal sections.

Section	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	T oc	23.53	24.45	26.57	27.42	28.43	29.29	26.71	26.17	27.1	25.36	23.45	22.24
	lv	2445.881	2443.765	2438.889	2436.934	2434.611	2432.633	2438.567	2439.809	2437.67	2441.672	2446.065	2448.848
1	E (l/s)	2.062962	2.064748	2.068876	2.070536	2.072512	2.074197	2.06915	2.068096	2.069911	2.066518	2.062807	2.060463
2	E (l/s)	1.518668	1.519982	1.523021	1.524243	1.525698	1.526938	1.523222	1.522447	1.523783	1.521285	1.518553	1.516828
3	E (l/s)	1.755785	1.757305	1.760818	1.762231	1.763912	1.765346	1.761051	1.760154	1.761699	1.758811	1.755652	1.753657
4	E (l/s)	0.210476	0.210659	0.21108	0.211249	0.211451	0.211623	0.211108	0.211	0.211185	0.210839	0.21046	0.210221
	<b>Total(l/s)</b>	<b>5.547891</b>	<b>5.552694</b>	<b>5.563796</b>	<b>5.568259</b>	<b>5.573572</b>	<b>5.578104</b>	<b>5.56453</b>	<b>5.561698</b>	<b>5.566578</b>	<b>5.557454</b>	<b>5.547473</b>	<b>5.541169</b>

The decrease in the command area due to evaporation loss is presented in the table 4.9 below.

Table 4.9 Command area lost due to evaporation loss

	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net command area	ha	15283	15283	15283	15283	15283	15283	15283	15283	15283	15283	15283	15283
Project supply (max)	l/s/ha	0.35	0.37	0.16	0.24	0.35	0.42	0.48	0.66	1.14	0.89	0.38	0.36
project supply (total)	l/s	5349	5655	2445	3668	5349	6419	7336	10087	17423	13602	5808	5502
Evaporation loss	l/s	5.55	5.55	5.56	5.57	5.57	5.58	5.56	5.56	5.57	5.56	5.55	5.54
Command area decreased per month	ha	15.85	15.01	34.77	23.20	15.924	13.28	11.59	8.43	4.88	6.24	14.59	15.39

Remark: Net command area and project supply was obtained from agronomy report of the project design.

#### 4.1.3.2 Seepage Losses from Canal due to increased surface area of the canal at Fantale

There are many methods to estimate seepage losses from canals among: - Kostiakov A.N. Formula (empirical formula) (Abu Gulul,1975)

When the measurements are not available to estimate seepage losses from earth canals or ditches. Kostiakov A.N formula can be used:-

$$S=s* \frac{Q * L}{100}$$

Where:-

S: Water losses per Km of canal length (in %).

L: Length of canal (Km).

Q: Water flow in (m<sup>3</sup>/s).

s: Water loss by seepage (% per Km), given by:

$$s = \frac{A_1}{Q^M} , \text{ where } A_1 \text{ and } M \text{ are empirical constants dependent on soil permeability}$$

as shown in Table (4.10).

Table 4.10 Values of constants A<sub>1</sub> and M (Abu Gulul,1975).

	Soil permeability		
	Low	Medium	High
A <sub>1</sub>	0.7	1.9	3.4
M	0.3	0.4	0.5

#### Geology along the main canal line

The geology of the canal route and surrounding area in general is occupied by basalt lava flows of different type and age. It is dark grey, fine-grained, highly vesicular, the cavities are generally open, vary in size and shape. Material description along the main canal line is summarized in Annex A

Seepage losses along the canal line using the material descriptions in the Annex of table A is summarized as follows in the table 4.11.

**Table 4. 11 seepage loss due increased of manning's roughness coefficient**

Section 1							
A (m2)	A1	Q (m3/s)	M	Q^M	s	L (km)	S=s*Q*L/100
0.3456	1.9	18	0.4	3.177672	0.597922	2.08	0.22386203
0.3456	1.9	18	0.4	3.177672	0.597922	1.65	0.17758286
0.3456	0.7	18	0.3	2.380026	0.294114	2.55	0.13499851
0.3456	1.9	18	0.4	3.177672	0.597922	3.644	0.39218906
0.3456	0.7	18	0.3	2.380026	0.294114	1.316	0.06966982
0.3456	0.7	18	0.3	2.380026	0.294114	1.08	0.05717584
0.3456	0.7	18	0.3	2.380026	0.294114	2.12	0.11223406
0.3456	1.9	18	0.4	3.177672	0.597922	0.98	0.10547346
0.3456	0.7	18	0.3	2.380026	0.294114	0.99	0.05241119
0.3456	0.7	18	0.3	2.380026	0.294114	0.63	0.03335257
0.3456	0.7	18	0.3	2.380026	0.294114	0.48	0.02541148
Total						17.52	1.3843608
Section 2							
0.6534	0.7	17	0.3	2.339563	0.299201	1.12	0.05696791
0.6534	0.7	17	0.3	2.339563	0.299201	0.24	0.01220741
0.6534	0.7	17	0.3	2.339563	0.299201	0.2	0.01017284
0.6534	1.9	17	0.4	3.105844	0.61175	0.16	0.0166396
0.6534	1.9	17	0.4	3.105844	0.61175	0.2	0.0207995
0.6534	3.4	17	0.5	4.123106	0.824621	0.86	0.12055961
0.6534	3.4	17	0.5	4.123106	0.824621	0.14	0.01962598
0.6534	3.4	17	0.5	4.123106	0.824621	0.18	0.02523341
0.6534	3.4	17	0.5	4.123106	0.824621	0.26	0.03644825
0.6534	3.4	17	0.5	4.123106	0.824621	0.72	0.10093363
0.6534	3.4	17	0.5	4.123106	0.824621	0.18	0.02523341
0.6534	3.4	17	0.5	4.123106	0.824621	0.4	0.05607424
0.6534	1.9	17	0.4	3.105844	0.61175	0.1	0.01039975
0.6534	1.9	17	0.4	3.105844	0.61175	1.32	0.13727672
0.6534	3.4	17	0.5	4.123106	0.824621	0.13	0.01822413
0.6534	1.9	17	0.4	3.105844	0.61175	0.45	0.04679888
0.6534	3.4	17	0.5	4.123106	0.824621	1.1	0.15420415
0.6534	3.4	17	0.5	4.123106	0.824621	0.85	0.11915775
0.6534	0.7	17	0.3	2.339563	0.299201	0.77	0.03916544

Total						9.38	1.02612261
Section 3							
0.3078	0.7	15	0.3	2.253343	0.31065	0.42	0.01957092
0.3078	1.9	15	0.4	2.954177	0.643157	0.4	0.03858943
0.3078	0.7	15	0.3	2.253343	0.31065	0.36	0.01677507
0.3078	0.7	15	0.3	2.253343	0.31065	3.08	0.14352007
0.3078	1.9	15	0.4	2.954177	0.643157	0.78	0.07524939
0.3078	0.7	15	0.3	2.253343	0.31065	0.66	0.0307543
0.3078	1.9	15	0.4	2.954177	0.643157	2.78	0.26819653
0.3078	1.9	15	0.4	2.954177	0.643157	0.15	0.01447104
0.3078	1.9	15	0.4	2.954177	0.643157	0.02	0.00192947
0.3078	1.9	15	0.4	2.954177	0.643157	2.296	0.22150332
0.3078	1.9	15	0.4	2.954177	0.643157	0.434	0.04186953
0.3078	1.9	15	0.4	2.954177	0.643157	4.42	0.42641319
Total						15.8	0.10149257
Section 4							
0.02535	0.7	7.2	0.3	1.808006	0.387167	0.99	0.02759726
0.02535	0.7	7.2	0.3	1.808006	0.387167	5.61	0.15638448
Total						6.6	0.18398174

The total discharge lost due to seepage is 0.632 l/s (sum of seepage from all sections).

Table 4.12 Command area lost due to seepage loss

	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Net command area	ha	15283	15283	15283	15283	15283	15283	15283	15283	15283	15283	15283	15283
Project supply (max)	l/s/ha	0.35	0.37	0.16	0.24	0.35	0.42	0.48	0.66	1.14	0.89	0.38	0.36
project supply (total)	l/s	5349	5655	2445	3668	5349	6419	7336	10087	17423	13602	5808	5502
Seepage loss (0.632)	ha loss per month	1.80	1.70	3.95	2.63	1.81	1.51	1.32	0.96	0.55	0.71	1.66	1.76

Remark: Command area and project supply was obtained from agronomy report of the project.

### 4.1.3.3 Siltation

Siltation of canal was observed during the research. In order to get the general insight to the siltation, velocity for the designed and calculated conditions was compared in table 4.13 below.

Table 4.13 Velocity for designed and calculated conditions

Section	V(m/s) designed	V(m/s) calculated
1	1.49	0.972
2	1.19	0.711
3	1.23	0.765
4	1.11	0.911

## 4.2 Tibila scheme

### Water Resource

The project was used to take irrigation water from Awash River. Diversion weir was constructed across the river at geographic coordinate of 557898 E longitude & 936473 N latitude and an average altitude of about 1291.607 m. Main canal intake site is located on the right bank of the Awash River. Awash River flows in the “V” shaped sharp narrow valley oriented towards Northeast. Canal intake was constructed to be having an equal elevation to an average active river flow surface.



Figure 4. 1 Head work location of the Tibila irrigation scheme.

### **General description of the project components**

During the reconnaissance visit, the researcher had visited the Irrigation and Drainage components of the project:

1. Diversion weir and appurtenant works
2. Head Regulator for the main canal
3. A net work of canal system comprising of main, primary, secondary, tertiary and field channels,
4. Necessary structures e.g. head and cross regulators of the off taking channels, drop structures, cross structures, etc.
5. A network of drainage system via field drains, tertiary drain, collector drain and intercepting drain for drainage of surplus water.

#### **4.2.1 The Main Canal conveyance efficiency of Tibila**

The Main Canal has total length of 32 km from the headwork up to the end of the command area with the designed conveyance capacity of 7.0 m<sup>3</sup>/sec. This canal is running from west to east crossing a number of gullies and streams by the constructed crossing structures. A number of seasonal major streams and Gully crossings, a lot of off-takes and other many cattle crossings were observed during the field visit.

The main canal supplies part of the night flow to the pond. Hence, the main canal operates for 24 hours while irrigation takes place for a maximum of 12 hours a day in the crop season. However, the main canal was supplying 1.53 m<sup>3</sup>/s at the main canal intake during the research was conducted. The command area developed to date of the research was estimated to 2200 ha.

#### **Canal Sections**

Two types of sections were constructed. Generally, canal sections are in fully cut or fill or partially cut and fill. The only open is the main canal, and secondary and tertiary canals are underground pipes. Depending on the geological formation, the main canal was constructed in:

- Trapezoidal canal section lined with polyethylene geo-membrane and 20 cm thick riverbed material filled in gabion.
- Rectangular section with concrete bed and masonry sides.

The trapezoidal section has been provided in reaches where the land formation was soil and there was no problem of excavation while rectangular section was constructed where the land formation was rocky.

#### **Canal Lining**

In most cases, canal lining is recommended to reduce water loss through seepage. Excessive seepage from unlined canal reduces the designed duty. For Tibila case, geo-membrane and cement concrete were used on main canal where there was doughty to excessive seepage.

#### **Conveyance efficiency**

The conveyance efficiency of the main canal was calculated in similar way for Fantale project. Discharge measurement has taken at different points on selected straight reaches of the canal. The efficiency calculated was 0.89, which is 89% (1.36 m<sup>3</sup>/s divided by 1.53 m<sup>3</sup>/s). Tibila project was started to operate in 2002 E.C and the canal stability is at good condition to date.

#### **4.2.2 Hydraulic effect on the conveyance of the main canal at Tibila**

Hydraulic parameters change has a great effect on the conveyance efficiency of the canals. In this study, the hydraulic effect on conveyance efficiency change (decrease) was manipulated on the change on the Manning's roughness coefficient ( $n$ ). The values of the calculated  $n$  for different sections on the main canal were between 0.085-0.093. However, the designed values range from 0.08-0.085 for the same canal on which  $n$  was calculated.

#### **4.2.3 Hydrologic effects on the conveyance of the main canal at Tibila Dependability and Water Availability Analysis**

The water availability and dependability for the project has been worked out based on hydrological data. The analysis indicated that about 7,000 ha could not be irrigated without storage using the diversion only.

Stream flow gauging station at Nura-era and Metahara were used. The mean annual discharge at Nura-era is 48 m<sup>3</sup>/sec, which varies between a minimum of 15.9 m<sup>3</sup>/sec to a maximum of 195.2 m<sup>3</sup>/sec where as at Metahara, the mean annual discharge is 34.2 m<sup>3</sup>/sec, which varies between a minimum of 0.7 m<sup>3</sup> /sec to a maximum of 225.1 m<sup>3</sup> /sec.

In order to account for the subsistence of aquatic life, downstream demand, etc the least minimum inflow of month has been checked. The shortage of adequate river flow data calls for the selection of 80% exceedance limit or 20% probability of water shortage.

##### **River Flows 80% Dependable**

Eighty percent dependable flows have been derived for Awash at the diversion sites. For Awash the 80% dependable flow has been calculated for key station (Nura-era station), which is downstream of the diversion site. The 80% dependable flows for this station is shown in table 4.14 below.

Table 4.14 80% dependable mean river flows (m<sup>3</sup>/sec) at Tibila

Site	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nura- era	27.5	27.5	27.9	29.7	26.6	27.9	39.2	55.2	57.4	35.4	24.2	25.37
Diversion site	26.2	26.2	26.6	28.2	25.3	26.6	37.2	52.4	54.5	33.6	22.9	24.1

Table 4.15 Estimated mean monthly 80% dependable flows at Diversion site (Mm<sup>3</sup>)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Flow	69.9	63.28	71.2	73.2	67.7	68.9	99.7	140	141	90.4	59.5	64.5	1165.2

### Water Availability Analysis

The method used to determine water availability in the project area was analyzing the Nura-era hydrological gauging station, water balance of the project area based on inflow and outflow characteristics, and field observations.

The hydrological characteristic of the area was described by the Awash River, which is draining the area. The river originates at elevation of 2900 m a.s.l around Arera-Kore ridge located at West of Ginchi town. Gauged stations on the river at different gauging stations were available. Among the gauging stations, Nura era gauging station was representative for the project area, for which data was available from 1976 to 2010. Irrigation abstraction for the project was downstream release from the Koka reservoir and additional stream flow contribution of the downstream catchment during rainy season. Climatic and geologic factors control the flow availability of a river. Important climatic elements are solar radiation, temperature, humidity, evaporation, and soil moisture, and vegetative growth, which subsequently affect the run off. The Diversion weir for the irrigation project is located just upstream of the gauging station (station 2017). The catchment area at this location is estimated to be about 13,469 km<sup>2</sup>. The Awash River catchment at Nura era station is 14,173 km<sup>2</sup>. Estimate of the 80% dependable flow of Awash River at diversion site were made. Out of the estimated dependable monthly flows the least minimum inflow of month must be released for downstream users and environmental purposes. However, as shown in the 80% dependable data of Awash River in certain dry years this much flow could not be available. Therefore, to take care of the uncertainties, mechanisms such as increasing storage in the catchment in a form of a pond and small dams, reduction of irrigation area when rainfall is below normal during the rainy season, and provision of night storage is necessary.

The flow availability analysis result using the following formula showed the result in the following tables.

$$K_t = R_t - F_t + K_{t-1}$$

Remark: If  $K_t$  is negative, storage is not required (surplus).

If  $K_t$  is positive, storage is required (deficit).

Table 4.16. Existing water users at downstream of diversion site

S/N	Water users	Annual Water utilization (Mm <sup>3</sup> )
1	Marti Jaju pump station	12.15
2	Hawas primary school	0.08
3	Addis Tesfa Hiwot JiJi	0.8
4	Kadir Ebo Jalo farmers association	0.27
5	Mahiber (Association)	0.13
6	Ababu Abdela farmers association	0.4
7	Mekbib Assefa farms	0.32
8	National mines corporation	0.09
9	Kibutitith company	0.32
10	Tesfa Hiwot Birhan church	0.01
11	Tirsol company	0.32
12	Samit Agro- industry P.L.C.	0.05
13	Addis Tesfa Hiwot	1.2
	<b>Total</b>	<b>16.14</b>

Source: Awash River Basin Authority, Amibara.

Table 4.17 Annual water Balance Analysis at the project area (in million metric cubes)

Inflow		Downstream irrigation water users ((Mm <sup>3</sup> )								Down-stream Release (Mm <sup>3</sup> )	Total demand (Mm <sup>3</sup> )	Flow balance	
Inflow 80%	Inflow 50%	Fantale	Tibila pump	Aba desco	Marti-jaju	Nura era	SSIP	MSF	Middle Awash			80%	50%
1010.1	1351.4	207.38	6.44	7.75	37.1	95.7	16.14	270.5	124.23	79.2	837.23	172.9	514

Existing irrigation water users in Awash River at upstream and downstream of Tibila irrigation project is presented in the following tables (4.18-4.22).

Table 4.18 Monthly water demand abstractions for irrigation at Metahara sugar factory (2011/12)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ual
Flow (Mm <sup>3</sup> )	20.443	24.235	18.981	21.421	27.664	27.769	20.490	4.796	30.013	26.906	23.171	24.615	70.504

Table 4.19 Monthly water demand abstractions for irrigation of Upper Awash Agro-Industry (2011/12)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Nura-era	7.780	7.606	7.706	7.801	8.705	8.315	7.490	7.688	9.830	8.043	7.386	7.369	95.719
Marti-Jaju	2.713	2.936	3.188	3.978	4.979	3.373	1.325	2.605	3.71	2.744	2.73	2.783	37.064
Tibila	0.387	0.345	0.325	0.257	3.888	0.299	0.061	0.009	0.084	0.206	0.302	0.276	6.439
Aba-desco	0.717	0.591	0.257	0.493	1.142	0.577	0.269	0.284	0.364	1.724	0.886	0.442	7.746
Flow(Mm <sup>3</sup> )	11.597	11.478	11.476	12.529	18.714	12.564	9.145	10.586	13.988	12.717	11.304	10.870	146.968

Table 4.20 Monthly water demand abstractions for irrigation of Wonji sugar factory (2011/2012)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Flow(Mm <sup>3</sup> )	7.052	7.825	6.565	7.130	7.500	6.983	4.750	0.536	2.959	7.653	7.552	7.525	74.030

Table 4.21 Monthly water demand abstractions for irrigation of Farmers surrounding Wonji area (2011/2012)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Flow Mm <sup>3</sup>	1.185	0.968	0.889	0.908	0.692	0.566	0.103	0.000	0.000	0.672	1.404	1.542	8.929

Table 4.22 Monthly water demand abstractions for irrigation of Middle Awash (2011/12)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Flow(Mm <sup>3</sup> )	0	0	0	13.44	18.42	18.74	10.734	22.334	17.038	11.367	8.853	3.308	124.234

Source: Awash River Basin Authority, Amibara.

Table 4.23 Monthly available flows and Flow balance analysis

Month	Inflow (Mm <sup>3</sup> ) at G.st mean	Inflow at G.st (80% dep flow)	Inflow (mean) at diversion (Mm <sup>3</sup> )	Inflow at diversion (80% dep flow) (Mm <sup>3</sup> )	Irrigation Demand(Mm <sup>3</sup> ) Downstream water users							D/s release (Mm <sup>3</sup> )	Flow balance (Mm <sup>3</sup> )	Flow balance (m <sup>3</sup> /s)
					Fantale	Tibila pump	Aba desco	Nura era	Merti jeju	MSF	Middle Awash gravity			
Jan	94.807	73.652	90.097	69.994	13.239	0.387	0.713	7.780	2.713	20.443	0	6.000	<b>18.712</b>	6.99
Feb	83.743	66.595	79.583	63.287	10.313	0.345	0.591	7.606	2.936	24.235	0	6.000	<b>10.714</b>	4.65
Mar	94.405	74.902	89.715	71.181	6.025	0.325	0.257	7.706	3.188	18.981	0	6.000	<b>28.699</b>	10.71
Apr	91.921	76.973	87.355	73.150	10.261	0.257	0.493	7.801	3.978	21.421	13.44	6.000	<b>9.498</b>	3.55
May	99.947	71.295	94.982	67.754	14.998	3.888	1.142	8.705	4.979	27.664	18.42	6.000	<b>-18.042</b>	<b>-6.73</b>
Jun	103.626	72.528	98.478	68.925	15.132	0.299	0.577	8.315	3.373	27.769	18.74	6.000	<b>-11.279</b>	<b>-4.21</b>
Jul	157.387	104.872	149.569	99.663	16.726	0.061	0.269	7.490	1.325	20.490	10.734	6.000	<b>36.568</b>	13.65
Aug	202.787	147.895	192.715	140.549	26.076	0.009	0.284	7.688	2.605	4.796	22.334	6.000	<b>68.906</b>	25.73
Sep	251.460	148.580	238.969	141.200	41.147	0.084	0.364	9.830	3.71	30.013	17.038	6.000	<b>29.784</b>	11.49
Oct	130.474	95.097	123.993	90.373	25.34	0.206	1.724	8.043	2.744	26.906	11.367	6.000	<b>8.890</b>	3.32
Nov	102.645	62.621	97.547	59.510	14.019	0.302	0.886	7.386	2.73	23.171	8.853	6.000	<b>-3.836</b>	<b>-1.48</b>
Dec	106.574	67.928	101.280	64.554	14.105	0.276	0.442	7.369	2.783	24.615	3.308	6.000	<b>5.656</b>	2.11
Annual	1519.77			1010.14	207.381	6.439	7.742	95.719	37.064	270.504	124.234		<b>183.420</b>	5.82

**Remark:** The flow balance in May, June & November months of the above table shows the deficit.

Table 4.24 Monthly Dependable Flow, Water Demand and Flow balance Analysis

Months	Monthly Flow,I 80% (Mm <sup>3</sup> )	Monthly Flow,I 50% (Mm <sup>3</sup> )	New Tibila Irrigation demand (Mm <sup>3</sup> )	Total Demand, D (Mm <sup>3</sup> )	Flow balance, 80% Kt (Mm <sup>3</sup> )	Flow balance, 50% Kt (Mm <sup>3</sup> )	Remark
Jan	69.994	86.029		51.279	-18.715	-34.750	Surplus
Feb	63.287	76.316		52.026	-11.261	-24.290	Surplus
Mar	71.181	88.776		42.482	-28.699	-46.294	Surplus
Apr	73.150	86.578		63.651	-9.499	-22.927	Surplus
May	67.754	85.159		85.796	18.042	0.636	Deficit
Jun	68.925	91.651	0.00	80.205	11.280	-11.445	Surplus
Jul	99.663	134.846	10.28	73.378	-26.285	-61.468	Surplus
Aug	140.549	178.616	52.92	122.709	-17.839	-55.907	Surplus
Sep	141.200	225.736	63.45	171.638	30.438	-54.097	Surplus
Oct	90.373	116.729	41.78	124.107	33.734	7.378	Deficit
Nov	59.510	87.639		63.347	3.836	-24.292	Surplus
Dec	64.554	93.419		58.898	-5.656	-34.521	Surplus

Remark: Irrigation demand for Tibila command area is taken from Agronomy report for 24 hrs supply

For 80% dependability irrigation requirement for Tibila cannot be meet in the months of May & June and September-November, but it will meet the requirement at 50% Dependability except for the months of May & October which shows deficit.

$K_t = D - I$ , where:  $K_t$ - Flow balance,  $D$ - Total water demand,  $I$ - Inflow

Since it couldn't get 10 days data of flow demand from Fentale, Tibila, Aba-desco, Marti-jaju, Nura era, MSF, Middle Awash and Awash Basin Authority, monthly basis data for water balance analysis have used.

### **4.3 Comparison of hydraulic and hydrologic effects**

As discussed above, the hydraulic and hydrologic effects have their own contributions in the conveyance inefficiency of the main canal for both schemes. However, the individual effect is not the same in the contribution to inefficiency. The calculated value for manning's roughness coefficient showed the great variation during the operation and design periods. For both schemes the value was increased which means that the discharge of the canal is decreased even though the scale was not equal for the two schemes.

Moreover, the increase in manning's roughness coefficient (hydraulic effect) results in the hydrologic effects (evaporation and seepage losses and siltation).

In other hand, there was the deficiency of the river flow in meeting the water requirement (demand) in some months for the projects. Over flow of the canals was controlled at the the weir site using the gate by adjusting the discharge released to the demand. Even in case when excess discharge is released, excess discharge is not overflow the canal bank because of the canal capacity is not attained to date. Therefore, hydraulic effect was pre-dominant for both projects.

### **4.4 Which factors to be considered at study or design stage in order to decrease the gap between the values of conveyance efficiency at design and operation stages?**

In the process of applying irrigation water to crops, water losses occur. These losses have to be taken into account when calculating the gross irrigation requirements of an irrigation project. This can be done through the use of an efficiency factor, which has to be estimated at the planning stage. Different types of irrigation systems have different levels of efficiency. The higher the irrigation efficiency, the larger the area that can be irrigated from a given finite water source, and the less the leaching of nutrients and damage to the soil and the more environmentally friendly the irrigation system. The water that is saved can be used for other productive purposes.



Lack of performance assessment implies absence of conventional performance management system, which suggests ineffectiveness and inefficiency in management.

To manage, you have to measure, if you do not you are only practicing. Inadequacy in flow of information hinders better understanding of performance of projects, diagnosis of root causes of problems, and effective improvement interventions.

Performance assessment is significantly done at the national, zonal and project levels or it will project, zonal or local specific. This situation makes it difficult to know, at any given point in time or over time, the performance of the sector at various levels.

The low efficiency indicates possible errors in the design or construction of infrastructure and the selection of inadequate flow regulating structures. This complicates operation and maintenance of the irrigation system. The difference between the planned and actual efficiency is partly due to a too optimistic estimate of the post-construction efficiency of water use, but also due to lack of skills or negligence of irrigators.

There is FAO guidelines on efficiencies with respect to construction materials in the literature, but the quality of construction for the specified material (s) will not be met on site. In addition, management practices must be considered in picking the value in the guidelines. Therefore, at stage study and design, the integration of management practices and construction quality with the guidelines is essential in effectively judging the efficiency will met in the time of operation.

## **5. Conclusion and Recommendations**

In the above sections results and discussions were presented. In this section, conclusion and recommendations on these results will be presented.

### **5.1 Conclusion**

Conveyance efficiency designed and the actual value obtained for most irrigation schemes show great difference, therefore, found to work under their expectation.

Therefore, this research was carried out to analysis hydraulic and hydrologic factors on conveyance efficiency of Fantale and Tibila irrigation schemes since the value used in the study or design stage is difficult to guess and moreover unlikely to meet the project conditions in their future state. The conveyance efficiency of Fantale scheme was much lower than for Tibila due to longer service life without maintenance and extensive length of main canal which makes conveyance efficiency more important than other efficiencies in affecting the overall irrigation performance. For Fantale, for canal after the asphalt road, conveyance efficiency is much lower than for the canal before the asphalt road due to high silt deposition and abrasion of the canal by grass.

Accordingly, hydraulic (conveyance characters like roughness coefficient, hydraulic radius and bed slope) showed great variation from the designed values and hydrologic factors (the variation in water depth which further increased the top width of water surface, seepage and evaporation losses which in turn due to increased top width of water surface) were made the conveyance efficiency taken at the design stage (95%) to fail to met in the current operation.

Moreover, the primary cause to the decrease of conveyance efficiency was high soil eroded and deposited in the canal which made increase in water depth in the canal. Soil deposited in the canal made the siltation problem which decreased flow velocity. Decrease in flow velocity made the scarcity of irrigation water in the command areas which will causes crop water stress which in turn result in low yield. The result obtained analyzing the flow balance of the river showed the deficit in meeting an irrigation water demand in May, June and November for Fantale while May, June and from September to November for Tibila irrigation scheme.

In general, hydrologic factor (soil eroded an entered canal) caused hydraulic factor (decreased in conveyance characteristic) and in turn hydraulic factors such as increase in manning's roughness coefficient and wetted perimeter caused hydrologic effects such as evaporation and seepage losses. Discharge lost due to evaporation and seepage resulted in loss of wide command area. Therefore, the value of conveyance efficiency taken directly from standard recommendations has great effect on the overall performance of these irrigation schemes.

## **5.2 Recommendations**

As can be seen in the result of hydrologic analysis, the 80% dependable flow of Awash River in certain dry years did not meet the Crop Water Requirement. Therefore, to take care of the uncertainties, mechanisms such as increasing storage in the catchment in a form of a pond and small dams, reduction of command area when demand is greater than the available discharge in the river, and provision of night storage is important.

If preventative measurement is not taken on the increased value of Manning's roughness coefficient while releasing of the total design discharge during the critical crop season, it will over flow the canal bank exceeding the free board designed.

In addition to the above recommendations, the seepage and evaporation losses along the increased surface area of the canal bank will require additional river inflow which is not meet even in the normal conditions without storage during off season. Therefore, maintenance of canal time to time is required. Moreover, watershed management of the basin (excessive soil erosion reduction in-situ and ex-situ) is recommended in order to decrease the amount of silt that deposited in the canal.

Agronomic and technological transfer factors were not analyzed in this study. Therefore, the two factors must also incorporate in the future study.

High value conveyance efficiency as obtained from different guidelines must not be applied without considering these factors.

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## **Annexes**

Table A Material description along the main canal line at Fantale

Chainage		Material Description	Remark
From (km) 0+000	To (km) 2+080	It contains Awash River flood plain deposit and recent vesicular scoraceous basalt flows	Nura8 era canal crossing is located at 2+080
2+080	3+730	Scoraceous vesicular basalt, intact rock is fresh and very strong shows massive appearance but at places lava flow structure like curved cleavage is observed.	Pockets of soil deposits of variable color and thickness are encountered  possibly indicating old planation or lake surfaces are observed, easy for excavation
3+730	6+280	Dark brown silty clay soil, the top 50 cm slightly stiff and sticky under lain by yellowish grey silty soil associated with gravel size calcret materials	Soil cut slope to be followed
6+280	9+924	Scoraceous vesicular basalt, intact rock is fresh and very strong shows massive appearance but at places flow structure is anticipated	At places not easily dozable
9+924	11+240	0-0.5 m thick, dark brown silty clay soil, underlain by calcret rich light grey silty clay soil	Homogeneous and uniform stable at 80 <sup>0</sup> cut slope in dry condition, irregular tensional crack on the wall of the canal
11+240	12+320	Top 0.5-m is brownish grey silty clay soil under lain by 0.5m thick horizontally layered sheet like trachyte flow again under lain by gravel size	Under cutting by erosional process observed at the base of calcrete formation

		light grey calcrete rich pumaceous agglomerate. Trachyte layer is variable in thickness and locally thin out and disappeared	indicating that susceptible to solutions process
12+320	14+ 440	Top 0.5m brownish grey silty clay soil underlain by light grey to yellowish grey carbonate cemented pumaceous agglomerate and again underlain by calcrete coated basalt.	At the base of the canal, locally fresh basalt is not easily dozable, and requires explosives.
14+440	15+420	Trachyte, pinkish grey characterized by horizontally layered sheet like flow structure highly fractured moderately weathered, underlain by pinkish grey to dark grey scoriaceous and obsidian rich basalt locally intercalated by trachyte, basalt and agglomeratic tuff layers.	Vertical Section at 15+380 indicating association of reworked volcanic flows and requires care during slope preparations for lining
15+420	16+410	Ignimbrite, greenish grey to light grey characterized by thinly layered horizontally oriented flow cleavage, moderately weathered weak to medium strong locally overlain by dark brown 0-40 cm thick silty clay soil. At places the top part is covered by thin light grey to yellowish grey loose and friable gravely silty soil of calcrete rich.	16+190 to 16+250 thin layer of yellowish grey gravely silty soil friable, loose and calcrete rich is overlying the ignimbrite
16+410	17+040	Variegated color pyroclastic agglomerates composed of reworked material cemented with calcrets	Easily dozable
17+040	18+640	Ignimbrite, greenish grey to light grey, moderately weathered, fractured weak rock	Dozable but not easily
18+640	18+880	Basalt, dark grey vesicular, slightly weathered appears as blocks strong to very strong	Not easily dozable
18+880	19+080	Silty clay soil, brownish grey friable	surface drainage

		loose, easily erodible needs to be protected	should be protected not to reach to the main canal
19+080	19+240	Basalt, dark grey vesicular, slightly weathered appears as blocks strong to very strong	Not easily dozable
19+240	19+440	Silty clay soil, brownish grey friable loose.	easily erodible to be protected
19+440	20+300	Basalt moderately weathered	ignimbrite exposed at the base of the canal not easily dozable
20+300	20+440	Sandy silty clay soil, light grey to brownish grey loose friable.	easily erodible alluvial deposit
20+440	20+620	Basalt dark grey, occurs as boulders, vesicular and the cavities are filled with calcite	Not easily shaped for canal lining
20+620	20+880	Ignimbrite, variegated color, the fragments contain basalt, pumice. At the base of the main canal moderately weathered basalt exposure is observed.	The formation is dozable
20+880	21+600	Silty sandy clay soil loose and friable with basalt rock fragments on top part	. Easily dozable
21+600	21+780	Silty sandy clay soil loose and friable,	Basalt is exposed at the base of the canal
21+780	22+180	Silty sandy clay soil, dark brown to light grey, loose and friable	Easily dozable
22+180	22+280	Basalt dark grey vesicular, moderately weathered, weak.	Dozable
22+280	23+600	Gravelly silty clay soil, light grey to yellowish grey loose and friable derived from volcanic ash	Possibly lacustrine deposit. Easily dozable
23+600	23+730	Basalt mixed with gravel and boulder size angular to sub rounded rock fragments of pumice and ash, cavities are generally filled with carbonate,	Dozable but no bank stability, requires retaining wall

23+730	24+180	Pumaceous ignimbrite with lithic fragments and fiamea light grey soft formation, dusty locally calcret rich with lithic fragments of rhyolite and basalt, sheet like structure horizontally layered	The occurrence of Blister structure located 10m offset to the east of the canal indicates the presence of volcanic conduit which is favorable for passage of canal water ,lining to be in especial care
24+180	25+280	Basalt, dark grey vesicular fragmented appears as boulders locally sheet like structure with horizontal layering flow cleavage. At places calcite cemented basaltic fragments and scoria of different shape and size at the base of the canal	Since the material is highly permeable .Should be protected not to have contact with surface water Retaining wall and material fill till required height of the wall
25+280	26+130	Gravelly sand clay soil mixed with boulder size sub angular rock fragments of ignimbrite, basalt, obsidian .Generally the soil part is loose and friable	possibly colluvial in origin
26+130	27+320	Gravelly silty clay soil yellowish grey, poorly sorted loose friable, easily dissolve in water and get in to suspension.	Possibly fluvio-lascustrine sedimentary origin
27+320	27+720	Ignimbrite greenish grey moderately weathered intercalated with layered obsidian fragments	Canal wall should be protected by stepped benching structure
27+720	28+080	Silty sandy soil, brownish grey to light grey up to 4m exposed thickness of alluvial deposit .At 27+960 blister structure formed of ignimbrite partly eroded is exposed at the center of the stream bed	Forms 90 <sup>0</sup> natural slope at the bank of the stream having 8 to 10m thick exposure
28+080	31+160	Intercalated fragments of trachyte,	The canal crosses at

		obsidian flow and ignimbrite, variegated color, fragments are locally cemented by carbonate	the margin between alluvial deposit and foot of the Birenti mountain chain
31+160	31+940	Colluvial deposit, yellowish grey, gravely silty clay loose and friable intercalated with angular rock fragments of trachyte .Fragments are generally coated with calcite	Rectangular shaped retaining wall to be constructed.
31+940	32+600	Silty clay soil, brownish grey, poorly sorted friable in dry condition and slightly sticky in wet condition, irregular cracks on the wall of the canal	Mesiba basin alluvial deposit homogenous and uniform no defined layering
32+600	35+380	Recent lava flows, dark grey vesicular scoraceous slightly weathered strong to very strong generally occurs as thin lava flow. Cavities are filled with carbonate	Not easily dozable
35+380	35+530	Lacustrine sediment, dark grey, silty sandy soil	easily dozable
35+530	35+550	Basalt, slightly vesicular, underlying the lacustrine sediments very strong, at places pockets of lacustrine deposits composed of silty clay is observed which is yellowish grey in color loose and friable.	Not easily dozable
35+550	37+846	Alternating basalt and lacustrine sediment, thin lacustrine soil of gravely silty clay is over lain by basalt slightly scoraceous and vesicular.	The canal passes at the margin between lava flow and sediment
37+846	38+280	Silty clay soil, light grey over lain by 0.5-1m thick dark brown silty clay soil. Gravel size calcrete fragments are randomly distributed.	Generally Stands 85 <sup>0</sup> soil cut slope in dry condition
38+280	43+690	Pumaceous lacustrine sediment composed of gravely Silty clay soil formed in fluvio-lacustrine environment, variegated color and	Vertical section indicating an alternating soil layer of variable texture

		<p>texture indicating different depositional episodes. At places loose friable soft light weight, easily erodable soil generally cemented with carbonate under lain by gravel sized sediments of similar compositions.</p>	<p>and color originated from lacustrine deposition however it forms 85° soil cut slope in dry condition. Easily erodable and dispersive.</p>
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## **Annex A1. Climatological Data for Tibila**

Table A1. Monthly Rainfall in mm      Region: Shoa      Station: Metehara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1996	27.6	0	97.3	35.1	80.5	26.5	205.1	100.5	52.6	1.6	7.5	0	634.3
1997	29.7	0	12.6	44.3	11.5	35.1	139.7	53.8	20.4	112.4	14.6	0	474.1
1998	0.8	18.1	76.6	34.2	14.9	4.7	78.2	135.6	54	78	0	0	495.1
1999	0	0	73.6	6.2	15.9	16.7	136.1	151.2	16.4	76.2	2.2	0	494.5
2000	0	0	1.8	20.7	36.9	29.6	135.9	152.7	46.8	47.3	11.9	9.4	493
2001	0	13.6	92.7	20.4	12.7	20.2	154.8	82.8	15.3	7.1	0	1.6	421.2
2002	2.6	0	73.3	19.3	9.3	10.2	43	80.8	16.8	0	0	21.2	276.5
2003	4.6	17.5	33.6	13.7	0	29.5	118.9	186	31	0	3.2	15.7	453.7
2004	35.1	3.2	80.6	142.4	0	21.2	85.3	123.9	39.3	15.9	4.5	0	551.4
2005	19.3	0	48	51.6	75.5	35.7	146.4	138.4	21.6	0	5.2	0	541.7
Mean	11.97	5.24	59.01	38.79	25.72	22.94	124.34	120.57	31.42	33.85	4.91	4.79	483.55
Max	35.1	18.1	97.3	142.4	80.5	35.7	205.1	186	54	112.4	14.6	21.2	
Min	0	0	1.8	6.2	0	4.7	43	53.8	15.3	0	0	0	
Std.	14.3	7.8	33.3	39.0	29.4	10.3	45.6	40.4	15.5	41.6	5.1	7.9	93.6
Cs	0.68	1.06	-0.71	2.44	1.33	-0.50	-0.18	-0.15	0.45	0.91	0.94	1.46	-0.88
K80%	-0.857	-0.850	-0.789	-0.719	-0.836	-0.808	-0.835	-0.833	-0.856	-0.854	-0.853	-0.850	
P80%	0.0	0.0	32.7	10.7	1.1	14.6	86.2	86.9	18.1	0.0	0.6	0.0	251.1

Table A2. Monthly Maximum Temperature in 0C

Element: Monthly Max. Temp. in <sup>0</sup>C      Region: Shoa      Station: Metehara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	31.6	34.2	34.4	34.4	34.3	34.7	32.3	32.4	34.1	34.3	31.9	31.1
1997	31.3	32.1	35.3	34.1	36.8	36.3	33.1	33.3	36	31.6	30.3	30.4
1998	30.1	32.9	33.9	36.9	37.2	38.1	34.3	31.5	33.8	32.9	32.3	31
1999	32	34.8	32.8	36.3	37.2	36.8	31.9	32	33.7	31.9	31.3	30.4
2000	31.8	33.2	35.1	35.7	36.8	37.3	33.2	31.5	33.7	32.7	32	30.9
2001	30.1	32.8	33.7	35.9	37.8	36.4	33	31.3	34.9	34.8	32.7	31.7
2002	30.9	33.9	34.5	36.3	38.3	37.8	36.6	33.6	35.4	35.3	33.5	31.4
2003	31.3	34.8	35.6	35.8	38.1	36.8	32	31.6	32.6	35.2	33.1	30.9
2004	32.3	32.4	34.1	33.4	37.8	36.9	33	33.1	34.7	33.4	32.5	31.2
2005	31.6	35	33.7	35.8	34.5	36.5	32.2	33.4	35	34.9	33.2	31.7
Mean	31.3	33.61	34.31	35.46	36.88	36.76	33.16	32.37	34.39	33.7	32.28	31.07
Max	32.3	35	35.6	36.9	38.3	38.1	36.6	33.6	36	35.3	33.5	31.7
Min	30.1	32.1	32.8	33.4	34.3	34.7	31.9	31.3	32.6	31.6	30.3	30.4

Table A3. Monthly Min. Temp. in °C

Element: Monthly Min. Temp. in °C Region: Shoa

Station: Metehara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1996	17.7	15.2	20.1	x	19.7	21.4	20.2	20.1	20	15.4	13.4	11.7	
1997	16	12.8	19.1	19.5	19.5	20.6	20.1	20.4	20.1	18.7	18.6	14.4	
1998	18.1	19.6	20.1	20.4	21.1	23.2	21.4	20	20.3	17.8	12.6	10	
1999	14.1	14.5	18.9	18.7	19.5	21.1	18.9	19.2	19.6	17.6	12.6	12.1	
2000	12.1	12.1	16.5	19.3	20.7	22.4	19.8	19.7	19.7	15.9	14.7	13	
2001	13.4	14.8	18.9	18.2	21	22.3	20	20.1	18.6	17.9	13.9	14.3	
2002	16.6	15.7	20.1	19.9	20.5	22.3	21.8	20	19.1	17.7	14.3	18	
2003	16	17.1	19.2	20.5	19.2	21.2	20.4	19.6	20	16.3	16	14.3	
2004	18.2	15.4	16.1	19.3	18.3	21.9	19.6	20.6	19.9	16.7	15.5	15.8	
2005	15.4	15.6	19.3	18.6	20.2	21.7	20.3	20	20.8	16.2	14.5	10.5	
Mean	15.76	15.28	18.83	19.38	19.97	21.81	20.25	19.97	19.81	17.02	14.61	13.41	
Max	18.2	19.6	20.1	20.5	21.1	23.2	21.8	20.6	20.8	18.7	18.6	18	
Min	12.1	12.1	16.1	18.2	18.3	20.6	18.9	19.2	18.6	15.4	12.6	10	
		Mean Temperature, °c											
	23.53	24.45	26.57	27.42	28.43	29.29	26.71	26.17	27.1	25.36	23.445	22.24	

Table A4. Monthly Rainfall @ Nura Era station in mm. Region: Shoa Station: Nura-era

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1996	158.7	0	111.7	99.2	82.1	42.8	109.5	143.7	66.3	12.2	30.8	0	857
1997	21.2	0	14.6	6	0	0	41	37.5	27.2	164.4	25.54	0	337.44
1999	0	0	31.3	0	14.8	39	125.8	153	24.7	140.5	4.4	0	533.5
2000	0	0	0	30.7	31.5	14.8	107.5	180.7	64.5	79.6	2.8	13.6	525.7
2001	0.3	26.5	131.8	22.3	28.3	31.5	142.6	102.8	83.4	0.8	0	0	570.3
2002	25.7	0	71.9	24.7	18.4	8.3	74.8	133	17.3	2.4	0	34.8	411.3
2003	27.8	33.4	47	23.6	1.6	82.4	112.2	240.9	70.2	0	3.7	35	677.8
2004	49.7	0	69.5	144	0	49.8	136.8	135.4	41.9	57.2	16	0.5	700.8
2005	77.9	0	68	36.8	74	37.6	148.6	111.8	21.1	1	11.2	0	588
Mean	40.1	6.7	60.6	43.0	27.9	34.0	111.0	137.6	46.3	50.9	10.5	9.3	578.0
Max	158.7	33.4	131.8	144	82.1	82.4	148.6	240.9	83.4	164.4	30.8	35	
Min	0	0	0	0	0	0	41	37.5	17.3	0	0	0	
Std.	51.4	13.3	43.0	47.3	30.8	24.7	34.5	55.6	25.0	64.4	11.4	15.2	155.5
Cs	1.80	1.69	0.30	1.60	1.07	0.58	-1.11	0.11	0.22	0.99	0.95	1.33	0.25
K80%	-0.799	0.809	0.853	0.817	0.849	0.857	0.745	0.846	0.851	-0.852	0.853	0.836	-0.8515
P80%	0.0	0.0	24.0	4.4	1.7	12.8	85.3	90.6	25.0	0.0	0.8	0.0	445.6

Table A5. Monthly Mean Maximum Temperature in °C station: Nura-era

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	total	Average
2000	x	x	x	x	x	x	x	x	x	x	30.2	29.2		
2001	28.1	31	31	33.2	35.3	33.9	31	30.4	32	32.3	30.4	29.3		
2002	28.8	31.4	32.2	33.8	36	35.7	34.2	31.5	32	32	30.8	28.6		
2003	29.4	32.6	33.6	32.7	35.7	34.4	31.3	30.8	31.4	32.3	31	29		
2004	30.2	29.9	31.8	32.1	35.3	34.5	31.5	31.3	32.3	31.3	27.2	29.3		
2005	29.5	32.5	32.7	33.4	33.2	34.8	31.7	32.3	33.3	32.4	30.3	28.7		
Mean	29.2	31.5	32.3	33.0	35.1	34.7	31.9	31.3	32.2	32.1	29.9	29.0		
Max	30.2	32.6	33.6	33.8	36	35.7	34.2	32.3	33.3	32.4	31	29.3		
Min	28.1	29.9	31	32.1	33.2	33.9	31	30.4	31.4	31.3	27.2	28.6		

Table A6. Monthly Rainfall Monthly Mean Minimum Temperature in °C

Station: Nura-era

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	total	Average
2000	x	x	x	x	x	x	x	x	x	x	13.5	12.3		
2001	12.4	13.3	17.8	16.8	18.3	18.6	16.3	18.2	16.8	15.9	11	11.5		
2002	15.1	13.4	18.1	18.4	20	21.7	21	19.5	18.9	16.4	13	16.6		
2003	14.8	15.3	17.7	19.2	17.8	20.6	19.8	19.1	18.8	14.6	14.4	12.6		
2004	16.6	13.8	14.8	18.5	18.8	21.3	19.1	19.3	18.5	14.3	13.5	13.9		
2005	14.8	13.4	18.2	17.1	19.6	20.4	19.4	19.3	19.7	15.4	12.4	9.4		
Mean	14.7	13.8	17.3	18.0	18.9	20.5	19.1	19.1	18.5	15.3	12.9	12.8		
Max	16.6	15.3	18.2	19.2	20	21.7	21	19.5	19.7	16.4	14.4	16.6		
Min	12.4	13.3	14.8	16.8	17.8	18.6	16.3	18.2	16.8	14.3	11	9.4		
Mean temperature, 0c														
	22	22.7	24.8	25.5	27	27.6	25.5	25.17	25.37	23.69	21.4	20.89		

## **Annex A2. Hydrological Data for Tibila**

Table A2.1. Summary of Hydrometric Discharge Data of Awash @ Nura-era Station

Station name: Awash @ Nura-era

Drainage area: 14,173 Sq.km

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	MMD
1975	I						71.230	126.961	220.03	259.056	118.802	77.370	88.345		
	II						91.889	99.196	127.09	180.002	82.601	44.684	48.870		
	III						11.770	20.279	48.017	65.577	8.412	13.021	12.597		
1976	I	95.247	97.388	110.917	118.736	133.65	89.360	112.527	163.76	154.658	89.777	49.685	56.828	1272.541	
	II	47.172	49.731	79.252	97.563	74.900	53.253	57.834	80.361	104.743	49.731	31.914	39.153		104.7
	III	19.743	21.375	20.823	23.656	18.179	16.683	15.254	39.153	35.437	10.205	10.973	14.339		
1977	I	65.706	53.677	54.388	75.027	62.328	72.391	123.531	191.52	211.606	136.862	193.576	159.910	1400.526	
	II	50.615	32.613	31.242	121.536	43.078	53.269	78.175	132.85	114.728	146.229	225.165	67.761		225.1
	III	12.600	13.457	14.343	17.678	15.259	10.208	24.850	21.940	48.031	23.081	53.299	19.853		
1978	I	115.223	131.95	143.823	120.386	103.288	120.926	177.215	157.47	137.046	143.256	102.862	131.777	1585.225	
	II	64.609	100.39	78.384	55.496	56.979	68.557	82.622	96.734	94.925	110.704	68.557	123.371		123.3
	III	6.078	15.525	8.130	20.358	24.025	23.487	28.486	32.014	37.590	31.416	20.358	34.451		
1979	I	129.691	111.47	105.309	104.689	112.649	116.160	154.197	204.94	203.560	155.472	127.164	139.636	1664.941	
	II	59.230	59.230	50.422	57.726	75.881	64.609	77.546	156.67	98.556	76.712	78.384	74.230		156.6
	III	15.986	20.868	10.795	27.344	27.344	25.664	43.493	56.979	53.299	48.303	30.821	43.493		
1980	I	100.953	83.686	91.059	77.772	63.595	73.594	110.380	105.63	86.285	90.628	59.983	55.174	998.740	
	II	69.296	42.257	44.400	82.629	28.939	34.290	111.597	82.629	67.898	75.054	26.458	24.105		111.5
	III	24.875	24.875	27.271	19.101	18.441	19.775	24.875	28.939	21.164	18.441	17.161	13.635		
1981	I	62.077	66.355	98.147	97.386	77.899	104.252	162.661	257.82	467.346	179.630	74.362	94.071	1742.00	
	I	29.794	54.813	91.994	76.535	39.156	86.581	165.362	303.19	295.971	180.187	48.871	54.813		303.19
	II	76.535	87.920	50.028	39.156	85.252	62.469	118.277	129.34	100.406	110.661	43.320	43.320		129.34
1983	I	14.758	13.635	21.164	21.878	22.607	29.794	25.660	47.730	38.153	31.549	17.794	19.775		
	II	78.229	75.118	101.19	93.009	221.136	122.140	167.510	229.06	505.991	151.541	118.573	142.169	2005.67	
	III	35.234	67.898	87.920	81.080	364.001	90.626	104.743	161.75	300.780	87.920	59.853	59.853		364.00
1984	I	20.463	21.878	26.458	21.164	24.875	27.271	31.549	42.257	33.362	27.271	21.878	48.871		
	II	119.339	70.184	72.756	68.198	92.014	89.737	110.700	166.43	167.166	97.101	89.540	92.753	1235.91	
	III	63.714	32.875	31.291	30.514	57.142	39.615	62.593	90.960	109.396	44.155	37.870	41.401		109.39
1985	I	31.291	24.655	24.655	21.965	23.290	28.989	32.078	39.615	35.327	28.242	31.291	29.746		
	II	81.356	70.618	75.041	94.181	94.600	79.955	106.431	271.37	413.679	80.877	67.820	75.089	1511.02	
	III	34.500	34.500	37.870	92.316	74.261	37.012	56.082	241.05	254.603	49.936	37.012	39.615		254.60
	II	26.060	24.655	21.965	26.777	27.505	28.989	28.989	46.042	51.944	25.353	21.318	20.680		
	II			64.845	46.042	47.969	93.683	232.238	103.53	106.446	57.142	38.738	40.503		

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	MMD
	III			32.875	32.078	30.514	35.327	49.936	31.291	28.989	29.746	28.989	29.746		
1987	I	77.525	75.716	101.04	113.241	137.597	96.391	90.895	148.61	129.247	81.349	73.989	80.019	1205.62	
	II	44.155	71.846	68.300	149.761	213.009	95.060	53.993	118.49	89.614	35.327	38.738	33.683		213.00
	III	22.623	24.655	23.290	32.078	26.060	26.060	23.290	32.875	27.505	26.777	21.318	26.060		
1988	I	93.632	77.859	80.952	76.409	45.761	41.266	117.571	156.51	223.215	112.504	57.731	60.553	1143.96	
	II	67.650	35.514	37.133	67.650	27.119	30.071	139.933	168.05	153.688	85.698	27.119	25.688		168.05
	III	31.590	25.688	21.575	21.575	9.983	7.203	16.533	20.267	28.580	27.119	15.940	20.267		
1989	I	64.138	68.843	68.738	90.915	84.441	105.640	175.681	220.82	380.909	123.742	90.987	98.441	1573.29	
	II	28.580	51.981	37.952	57.671	36.320	56.707	98.979	113.67	279.430	106.208	48.316	44.755		279.43
	III	21.575	21.575	18.990	17.745	28.580	30.071	46.522	61.589	112.165	18.364	22.242	28.580		
1990	I	78.073	115.56	116.60	116.971	83.047	83.831	110.733	176.50	323.263	120.174	101.677	74.444	1500.89	
	II	32.361	109.16	122.96	67.650	35.514	55.749	82.630	142.56	221.975	145.971	159.960	34.715		221.97
	III	18.990	28.580	29.322	32.361	24.983	26.830	30.071	18.990	72.868	30.827	28.580	22.242		
1991	I	72.461	84.123	129.86	114.915	113.471	78.940	141.541	168.49	364.203	127.343	122.656	118.479	1636.49	
	II	28.580	51.981	79.323	80.420	58.641	38.779	159.960	201.55	407.466	90.626	73.929	55.749		407.46
	III	25.688	25.688	31.590	19.624	19.624	22.915	30.827	30.827	49.223	33.139	36.320	28.580		
1992	I	163.851	117.32	69.154	67.236	88.614	68.717	91.052	147.36	219.718	91.098	61.338	67.889	1253.35	
	II	87.920	69.719	48.316	100.406	43.014	85.252	140.882	104.74	197.588	109.167	25.688	39.612		197.58
	III	43.014	38.779	13.651	18.364	27.846	13.651	17.745	25.688	31.590	24.286	18.364	15.940		
1993	I	85.226	75.981	70.133	76.423	97.532	94.855	136.366			134.679	77.266	79.565		
	II	121.391	73.929	34.715	147.686	64.592	65.606	134.232	112.29		100.406	41.300	34.715		
	III	20.267	23.597	20.267	19.624	22.915	20.267	29.322			27.119	9.017	25.688		
1994	I	89.145	71.297	85.967	83.723	66.917	103.953	204.275	194.60	161.656		109.163	122.877		
	II	48.316	36.320	43.014	52.914	30.071	156.405	226.171	119.82	94.759		67.650	65.606		
	III	28.580	24.286	27.846	24.286	20.267	27.119	43.014	51.981	37.9522		30.827	33.139		
1995	I	114.318	68.123	109.99	85.946	112.172	192.407	315.711	365.10	300.872	227.661	209.617	210.037	2311.97	
	II	58.641	31.590	163.55	67.650	82.630	110.661	160.138	209.61	142.569	113.679	85.252	85.252		209.61
	III	32.361	24.286	25.688	28.580	29.322	41.300	82.630	79.323	73.929	68.682	74.996	73.929		
1996	I	115.878	68.123	108.86	85.946	112.172	192.407	315.696	365.10	300.872	227.661	209.617	210.037	2312.38	
	II	58.641	31.590	163.55	67.650	82.630	110.661	159.960	209.61	142.569	113.679	85.252	85.252		209.61
	III	32.361	24.286	25.688	28.580	29.322	41.300	82.630	79.323	73.929	68.682	74.996	73.929		

Remark: I-monthly runoff in million m<sup>3</sup>

II- Maximum Discharge in m<sup>3</sup>/sec

III- Minimum Discharge in m<sup>3</sup>/sec

MMD- Maximum means daily discharge in m<sup>3</sup>/sec

Table A2.2 Summary of Hydrometric Discharge Data of Awash @ Metahara Station

Station name: Metahara Basin: Awash Drainage area: 16417 Sq.km

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1973	I	1.185	0.835	1.844	0.908	1.115	10.239	47.318	97.875	53.486	14.982	2.080		
1974	I	0.775	0.449		0.579	2.396	19.881	60.552	58.004	64.055	23.586	3.788	1.065	
1975	I	1.066	0.774	0.871	1.520	3.261	5.481	57.141	1.291	1.249	1.291	1.249	1.365	76.559
1976	I	1.291	1.166	1.291	1.249	1.291	1.249			63.045	15.490	1.796	1.291	
1977	I	0.759	0.420	1.196	0.512	0.705	3.259	35.035	67.621	71.784	22.382	1.196	1.023	205.892
1978	I	0.650	0.778	0.484	0.674	0.999	14.424	55.238	73.205	48.889	10.567	1.480	0.887	208.275
1979	I	0.782	0.547	1.046	1.382	2.725	5.548	49.432	40.892	34.447	20.845	4.428	1.140	163.214
1980	I	1.037	1.116	0.818	1.171	0.516	1.949	24.484	50.128	53.450	25.642	19.051	1.488	180.850
1981	I	1.390	0.963	1.394	2.320	3.306	7.475	31.168	47.923	46.051	37.899	8.974	5.181	194.044
1982	I	65.369	52.459	50.966	54.297	72.889	53.352	97.003	198.76	118.12	100.17	52.904	1.764	918.05
1983	I	35.159	35.669	45.034	44.214	132.17	79.551	138.02	206.31	408.82	155.22	105.25	57.095	1442.5
1984	I	100.69	40.102	38.598	27.892	59.11	62.15	75.077	139.04	127.18	54.886	56.124	131.627	912.47
1985	I	39.597	35.289	33.977	57.234	85.712	44.198	31.378	54.508	48.332	34.87	43.049	56.552	564.7
1986	I	73.132	70.915	90.019	74.141	75.342	103.46	183.74	145	86.619	49.479	57.386	51.697	1060.9
1987	I	49.614	42.786	86.783	71.081	50.049	33.537	26.859	93.359	57.876	16.43	14.496	62.365	605.24
1988	I	24.34	16.291	14.54	26.405	4.506	4.772	39.913	101.82	180.82	63.48	13.501	13.429	503.82

1989	I	17.171	24.872	20.308	57.274	34.662	43.003	122.58	144.54	316.72	76.544	52.864	14.07	924.61
1990	I	42.248	111.66	69.825	72.085	48.538	25.358	41.282	58.681	45.757	11.739	47.192	61.898	
1991	I	35.499	50.861	85.225	69.06	68.744	39.858	99.189	158.55	374.86	97.152	99.052	41.722	1219.8
1992	I	132.35	132.73	33.777	50.575	56.236	35.267	56.686	118.19	292.77	85.059	46.476	85.526	1125.6
1993	I	83.729	76.633	48.589	59.52	122.17	100.09	131.74	361.72	543.62	165.39	67.749	57.416	1818.4
1994	I	65.562	52.794	53.016	55.056	58.64	53.728	150.46	123.73	129.75	70.473	44.087	71.913	929.21
1995	I	37.829	51.942	103.17	59.794	44.127	77.858	160.66	187.97	130.09	42.88	41.505	45.412	983.23
1996	I	50.143	39.527	81.997	48.031	51.119	55.644	92.246		521.34	62.846	26.88	40.828	
1997	I	68.584	47.054	70.409	80.519	59.639	59.891	116.99	131.98	47.074	45.38	30.679	58.246	816.45
1998	I	25.26	25.262	41.682	29.87	24.441	25.653	64.81	578.51	388.91	189.32	53.317	18.913	1466
1999	I	63.857	56.653	71.72	60.273	73.062	99.805	200.15	419	206.88	199.23	86.246	63.277	1600.2
2000	I	91.24	73.963	71.544	70.04	133.19	109.63	105.41	200.82	161.02	161.3	94.403	73.613	1346.2
2001	I	75.969	72.021	72.92	61.151	138.62	67.056	97.91	64.256	55.272	70.703	80.011	66.986	922.87
2002	I	87.557	63.731	73.74	68.402	62.603	68.437	93.783	157.82	93.22	48.126	18.956	83.171	919.55
2003	I	32.424	25.295	33.699	39.865	25.914	7.72	93.861	58.176	52.442	74.123	48.39	22.384	514.29
2004	I	65.305	50.899	68.169	95.635	4.039	40.887	52.401	46.183	44.293	54.279	36.524	1.922	560.54

Table A2.3. Mean monthly flow data

Station name:		Metahara					Basin	Awash	Drainage area		16417	Sq.km.	
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
					in Mm <sup>3</sup>								
1973	65.600	34.390	25.680	21.120	24.550	24.240	67.560	96.970	148.330	72.050	31.330	32.400	644.220
1974	39.680	22.620	47.200	54.450	38.870	104.650	141.030	216.830	309.720	65.510	20.360	66.660	1127.580
1975	100.570	77.350	65.410	58.680	49.010	59.440	148.000	373.820	583.460	110.000	37.410	48.240	1711.390
1976	67.910	57.600	87.700	102.110	139.670	59.470	115.110	213.550	174.170	62.440	33.180	27.170	1140.080
1977	55.980	49.850	45.950	46.690	54.090	56.630	105.120	182.910	216.190	117.900	221.000	145.730	1298.040
1978	105.000	118.94	153.370	92.270	71.700	78.130	179.110	148.660	101.550	123.290	73.350	109.880	1355.250
1979	133.040	99.860	67.340	55.420	66.560	55.540	81.890	152.650	165.930	70.370	57.440	63.120	1069.160
1980	65.910	59.600	52.560	36.450	33.640	42.720	94.610	89.260	56.740	33.810	22.750	28.690	616.740
1981	31.720	38.140	68.150	85.040	43.280	55.100	132.710	234.300	350.360	189.200	65.600	65.000	1358.600
1982	65.369	52.459	50.966	54.297	72.889	53.352	97.003	198.763	118.123	100.165	52.904	1.764	918.054
1983	35.159	35.669	45.034	44.214	132.171	79.551	138.019	206.308	408.819	155.219	105.249	57.095	1442.507
1984	100.687	40.102	38.598	27.892	59.11	62.15	75.077	139.035	127.18	54.886	56.124	131.627	912.468
1985	39.597	35.289	33.977	57.234	85.712	44.198	31.378	54.508	48.332	34.87	43.049	56.552	564.696
1986	73.132	70.915	90.019	74.141	75.342	103.463	183.74	145.002	86.619	49.479	57.386	51.697	1060.935
1987	49.614	42.786	86.783	71.081	50.049	33.537	26.859	93.359	57.876	16.43	14.496	62.365	605.235
1988	24.34	16.291	14.54	26.405	4.506	4.772	39.913	101.824	180.819	63.48	13.501	13.429	503.820

1989	17.171	24.872	20.308	57.274	34.662	43.003	122.577	144.542	316.72	76.544	52.864	14.07	924.607
1990	42.248	111.664	69.825	72.085	48.538	25.358	41.282	58.681	45.757	11.739	47.192	61.898	636.267
1991	35.499	50.861	85.225	69.06	68.744	39.858	99.189	158.548	374.861	97.152	99.052	41.722	1219.771
1992	132.351	132.728	33.777	50.575	56.236	35.267	56.686	118.188	292.774	85.059	46.476	85.526	1125.643
1993	83.729	76.633	48.589	59.52	122.172	100.094	131.738	361.715	543.617	165.394	67.749	57.416	1818.366
1994	65.562	52.794	53.016	55.056	58.64	53.728	150.458	123.733	129.754	70.473	44.087	71.913	929.214
1995	37.829	51.942	103.17	59.794	44.127	77.858	160.658	187.968	130.089	42.88	41.505	45.412	983.232
1996	50.143	39.527	81.997	48.031	51.119	55.644	92.246	159.976	521.342	62.846	26.88	40.828	1230.579
1997	68.584	47.054	70.409	80.519	59.639	59.891	116.992	131.983	47.074	45.38	30.679	58.246	816.450
1998	25.26	25.262	41.682	29.87	24.441	25.653	64.81	578.51	388.911	189.323	53.317	18.913	1465.952
1999	63.857	56.653	71.72	60.273	73.062	99.805	200.148	419.002	206.877	199.232	86.246	63.277	1600.152
2000	91.24	73.963	71.544	70.04	133.193	109.63	105.407	200.82	161.023	161.304	94.403	73.613	1346.180
2001	75.969	72.021	72.92	61.151	138.616	67.056	97.91	64.256	55.272	70.703	80.011	66.986	922.871
Mean	63.54	57.51	61.98	57.96	66.01	58.96	106.80	184.68	218.91	89.56	57.78	57.28	1080.97
St.dev.	30.45	29.04	28.44	19.19	35.76	26.73	45.95	116.73	158.98	52.91	39.86	32.30	350.82
Cv	0.48	0.51	0.46	0.33	0.54	0.45	0.43	0.63	0.73	0.59	0.69	0.56	0.32

## **Annex B1. Climatological Data for Fantale**

Table B1.1 Monthly Rainfall in mm.

Element: Monthly Rainfall in mm

Region: Shoa

Station: Metehara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1996	27.6	0	97.3	35.1	80.5	26.5	205.1	100.5	52.6	1.6	7.5	0	634.3
1997	29.7	0	12.6	44.3	11.5	35.1	139.7	53.8	20.4	112.4	14.6	0	474.1
1998	0.8	18.1	76.6	34.2	14.9	4.7	78.2	135.6	54	78	0	0	495.1
1999	0	0	73.6	6.2	15.9	16.7	136.1	151.2	16.4	76.2	2.2	0	494.5
2000	0	0	1.8	20.7	36.9	29.6	135.9	152.7	46.8	47.3	11.9	9.4	493
2001	0	13.6	92.7	20.4	12.7	20.2	154.8	82.8	15.3	7.1	0	1.6	421.2
2002	2.6	0	73.3	19.3	9.3	10.2	43	80.8	16.8	0	0	21.2	276.5
2003	4.6	17.5	33.6	13.7	0	29.5	118.9	186	31	0	3.2	15.7	453.7
2004	35.1	3.2	80.6	142.4	0	21.2	85.3	123.9	39.3	15.9	4.5	0	551.4
2005	19.3	0	48	51.6	75.5	35.7	146.4	138.4	21.6	0	5.2	0	541.7
Mean	11.97	5.24	59.01	38.79	25.72	22.94	124.34	120.57	31.42	33.85	4.91	4.79	483.55
Max	35.1	18.1	97.3	142.4	80.5	35.7	205.1	186	54	112.4	14.6	21.2	
Min	0	0	1.8	6.2	0	4.7	43	53.8	15.3	0	0	0	
Std.	14.3	7.8	33.3	39.0	29.4	10.3	45.6	40.4	15.5	41.6	5.1	7.9	93.6
Cs	0.68	1.06	-0.71	2.44	1.33	-0.50	-0.18	-0.15	0.45	0.91	0.94	1.46	-0.88
K80%	-0.857	-0.850	-0.789	-0.719	-0.836	-0.808	-0.835	-0.833	-0.856	-0.854	-0.853	-0.850	
P80%	0.0	0.0	32.7	10.7	1.1	14.6	86.2	86.9	18.1	0.0	0.6	0.0	251.1

Table B1.2 Monthly Maximum Temperature Region: Shoa Station: Metehara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	31.6	34.2	34.4	34.4	34.3	34.7	32.3	32.4	34.1	34.3	31.9	31.1
1997	31.3	32.1	35.3	34.1	36.8	36.3	33.1	33.3	36	31.6	30.3	30.4
1998	30.1	32.9	33.9	36.9	37.2	38.1	34.3	31.5	33.8	32.9	32.3	31
1999	32	34.8	32.8	36.3	37.2	36.8	31.9	32	33.7	31.9	31.3	30.4
2000	31.8	33.2	35.1	35.7	36.8	37.3	33.2	31.5	33.7	32.7	32	30.9
2001	30.1	32.8	33.7	35.9	37.8	36.4	33	31.3	34.9	34.8	32.7	31.7
2002	30.9	33.9	34.5	36.3	38.3	37.8	36.6	33.6	35.4	35.3	33.5	31.4
2003	31.3	34.8	35.6	35.8	38.1	36.8	32	31.6	32.6	35.2	33.1	30.9
2004	32.3	32.4	34.1	33.4	37.8	36.9	33	33.1	34.7	33.4	32.5	31.2
2005	31.6	35	33.7	35.8	34.5	36.5	32.2	33.4	35	34.9	33.2	31.7
Mean	31.3	33.61	34.31	35.46	36.88	36.76	33.16	32.37	34.39	33.7	32.28	31.07
Max	32.3	35	35.6	36.9	38.3	38.1	36.6	33.6	36	35.3	33.5	31.7
Min	30.1	32.1	32.8	33.4	34.3	34.7	31.9	31.3	32.6	31.6	30.3	30.4

Table B.3 Monthly Min Temperature Region: Shoa Station: Metehara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	17.7	15.2	20.1	x	19.7	21.4	20.2	20.1	20	15.4	13.4	11.7
1997	16	12.8	19.1	19.5	19.5	20.6	20.1	20.4	20.1	18.7	18.6	14.4
1998	18.1	19.6	20.1	20.4	21.1	23.2	21.4	20	20.3	17.8	12.6	10
1999	14.1	14.5	18.9	18.7	19.5	21.1	18.9	19.2	19.6	17.6	12.6	12.1
2000	12.1	12.1	16.5	19.3	20.7	22.4	19.8	19.7	19.7	15.9	14.7	13
2001	13.4	14.8	18.9	18.2	21	22.3	20	20.1	18.6	17.9	13.9	14.3
2002	16.6	15.7	20.1	19.9	20.5	22.3	21.8	20	19.1	17.7	14.3	18
2003	16	17.1	19.2	20.5	19.2	21.2	20.4	19.6	20	16.3	16	14.3
2004	18.2	15.4	16.1	19.3	18.3	21.9	19.6	20.6	19.9	16.7	15.5	15.8
2005	15.4	15.6	19.3	18.6	20.2	21.7	20.3	20	20.8	16.2	14.5	10.5
Mean	15.76	15.28	18.83	19.38	19.97	21.81	20.25	19.97	19.81	17.02	14.61	13.41
Max	18.2	19.6	20.1	20.5	21.1	23.2	21.8	20.6	20.8	18.7	18.6	18
Min	12.1	12.1	16.1	18.2	18.3	20.6	18.9	19.2	18.6	15.4	12.6	10
Mean Temperature, 0c												
	23.53	24.45	26.57	27.42	28.43	29.29	26.71	26.17	27.1	25.36	23.445	22.24

Table B.4 monthly rainfall in mm. Region: Shoa Station: Nura-era

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1996	158.7	0	111.7	99.2	82.1	42.8	109.5	143.7	66.3	12.2	30.8	0	857
1997	21.2	0	14.6	6	0	0	41	37.5	27.2	164.4	25.54	0	337.44
1999	0	0	31.3	0	14.8	39	125.8	153	24.7	140.5	4.4	0	533.5
2000	0	0	0	30.7	31.5	14.8	107.5	180.7	64.5	79.6	2.8	13.6	525.7
2001	0.3	26.5	131.8	22.3	28.3	31.5	142.6	102.8	83.4	0.8	0	0	570.3
2002	25.7	0	71.9	24.7	18.4	8.3	74.8	133	17.3	2.4	0	34.8	411.3
2003	27.8	33.4	47	23.6	1.6	82.4	112.2	240.9	70.2	0	3.7	35	677.8
2004	49.7	0	69.5	144	0	49.8	136.8	135.4	41.9	57.2	16	0.5	700.8
2005	77.9	0	68	36.8	74	37.6	148.6	111.8	21.1	1	11.2	0	588
Mean	40.1	6.7	60.6	43.0	27.9	34.0	111.0	137.6	46.3	50.9	10.5	9.3	578.0
Max	158.7	33.4	131.8	144	82.1	82.4	148.6	240.9	83.4	164.4	30.8	35	
Min	0	0	0	0	0	0	41	37.5	17.3	0	0	0	
Std.	51.4	13.3	43.0	47.3	30.8	24.7	34.5	55.6	25.0	64.4	11.4	15.2	155.5
Cs	1.80	1.69	0.30	1.60	1.07	0.58	-1.11	0.11	0.22	0.99	0.95	1.33	0.25
K80%	-0.799	0.809	0.853	0.817	0.849	0.857	0.745	0.846	0.851	-0.852	0.853	0.836	-0.8515
P80%	0.0	0.0	24.0	4.4	1.7	12.8	85.3	90.6	25.0	0.0	0.8	0.0	445.6

## **Annex B2. Hydrometric Data for Fantale**

Table B2.1 Summary of hydrometric discharge data of awash @ Nura Hera station

Station name: Awash @ Nura-era

Drainage area: 14,173 Sq.km

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	MMD
1975	I						71.230	126.961	220.037	259.056	118.802	77.370	88.345		
	II						91.889	99.196	127.092	180.002	82.601	44.684	48.870		
	III						11.770	20.279	48.017	65.577	8.412	13.021	12.597		
1976	I	95.247	97.388	110.917	118.736	133.654	89.360	112.527	163.764	154.658	89.777	49.685	56.828	1272.5	
	II	47.172	49.731	79.252	97.563	74.900	53.253	57.834	80.361	104.743	49.731	31.914	39.153		104.74
	III	19.743	21.375	20.823	23.656	18.179	16.683	15.254	39.153	35.437	10.205	10.973	14.339		
1977	I	65.706	53.677	54.388	75.027	62.328	72.391	123.531	191.525	211.606	136.862	193.576	159.910	1400.5	
	II	50.615	32.613	31.242	121.536	43.078	53.269	78.175	132.858	114.728	146.229	225.165	67.761		225.16
	III	12.600	13.457	14.343	17.678	15.259	10.208	24.850	21.940	48.031	23.081	53.299	19.853		
1978	I	115.22	131.95	143.823	120.386	103.288	120.926	177.215	157.474	137.046	143.256	102.862	131.777	1585.2	
	II	64.609	100.39	78.384	55.496	56.979	68.557	82.622	96.734	94.925	110.704	68.557	123.371		123.37
	III	6.078	15.525	8.130	20.358	24.025	23.487	28.486	32.014	37.590	31.416	20.358	34.451		
1979	I	129.69	111.47	105.309	104.689	112.649	116.160	154.197	204.944	203.560	155.472	127.164	139.636	1664.9	
	II	59.230	59.230	50.422	57.726	75.881	64.609	77.546	156.678	98.556	76.712	78.384	74.230		156.67
	III	15.986	20.868	10.795	27.344	27.344	25.664	43.493	56.979	53.299	48.303	30.821	43.493		
1980	I	100.95	83.686	91.059	77.772	63.595	73.594	110.380	105.631	86.285	90.628	59.983	55.174	998.74	
	II	69.296	42.257	44.400	82.629	28.939	34.290	111.597	82.629	67.898	75.054	26.458	24.105		111.59
	III	24.875	24.875	27.271	19.101	18.441	19.775	24.875	28.939	21.164	18.441	17.161	13.635		
1981	I	62.077	66.355	98.147	97.386	77.899	104.252	162.661	257.823	467.346	179.630	74.362	94.071	1742.0	
	II	29.794	54.813	91.994	76.535	39.156	86.581	165.362	303.199	295.971	180.187	48.871	54.813		303.19
	III	76.535	87.920	50.028	39.156	85.252	62.469	118.277	129.345	100.406	110.661	43.320	43.320		129.34
	III	14.758	13.635	21.164	21.878	22.607	29.794	25.660	47.730	38.153	31.549	17.794	19.775		
1983	I	78.229	75.118	101.19	93.009	221.136	122.140	167.510	229.065	505.991	151.541	118.573	142.169	2005.6	
	II	35.234	67.898	87.920	81.080	364.001	90.626	104.743	161.751	300.780	87.920	59.853	59.853		364.00
	III	20.463	21.878	26.458	21.164	24.875	27.271	31.549	42.257	33.362	27.271	21.878	48.871		
1984	I	119.33	70.184	72.756	68.198	92.014	89.737	110.70	166.430	167.166	97.101	89.540	92.753	1235.9	
	II	63.714	32.875	31.291	30.514	57.142	39.615	62.593	90.960	109.396	44.155	37.870	41.401		109.39
	III	31.291	24.655	24.655	21.965	23.290	28.989	32.078	39.615	35.327	28.242	31.291	29.746		

1985	I	81.356	70.618	75.041	94.181	94.600	79.955	106.43	271.372	413.679	80.877	67.820	75.089	1511.0	
	II	34.500	34.500	37.870	92.316	74.261	37.012	56.082	241.058	254.603	49.936	37.012	39.615		254.60
	III	26.060	24.655	21.965	26.777	27.505	28.989	28.989	46.042	51.944	25.353	21.318	20.680		
	II			64.845	46.042	47.969	93.683	232.23	103.538	106.446	57.142	38.738	40.503		
	III			32.875	32.078	30.514	35.327	49.936	31.291	28.989	29.746	28.989	29.746		
1987	I	77.525	75.716	101.04	113.241	137.59	96.391	90.895	148.616	129.247	81.349	73.989	80.019	1205.6	
	II	44.155	71.846	68.300	149.761	213.00	95.060	53.993	118.493	89.614	35.327	38.738	33.683		213.00
	III	22.623	24.655	23.290	32.078	26.060	26.060	23.290	32.875	27.505	26.777	21.318	26.060		
1988	I	93.63	77.859	80.952	76.409	45.761	41.266	117.57	156.515	223.215	112.50	57.731	60.553	1143.9	
	II	67.65	35.514	37.133	67.650	27.119	30.071	139.93	168.056	153.688	85.698	27.119	25.688		168.05
	III	31.59	25.688	21.575	21.575	9.983	7.203	16.533	20.267	28.580	27.119	15.940	20.267		
1989	I	64.13	68.843	68.738	90.915	84.441	105.64	175.68	220.821	380.909	123.74	90.987	98.441	1573.2	
	II	28.580	51.981	37.952	57.671	36.320	56.707	98.979	113.679	279.430	106.20	48.316	44.755		279.43
	III	21.575	21.575	18.990	17.745	28.580	30.071	46.522	61.589	112.165	18.364	22.242	28.580		
1990	I	78.073	115.56	116.60	116.971	83.047	83.831	110.73	176.507	323.263	120.17	101.67	74.444	1500.8	
	II	32.361	109.16	122.96	67.650	35.514	55.749	82.630	142.569	221.975	145.97	159.96	34.715		221.97
	III	18.990	28.580	29.322	32.361	24.983	26.830	30.071	18.990	72.868	30.827	28.580	22.242		
1991	I	72.461	84.123	129.86	114.915	113.47	78.940	141.54	168.496	364.203	127.34	122.65	118.47	1636.4	
	II	28.580	51.981	79.323	80.420	58.641	38.779	159.96	201.559	407.466	90.626	73.929	55.749		407.46
	III	25.688	25.688	31.590	19.624	19.624	22.915	30.827	30.827	49.223	33.139	36.320	28.580		
1992	I	163.85	117.32	69.154	67.236	88.614	68.717	91.052	147.363	219.718	91.098	61.338	67.889	1253.3	
	II	87.920	69.719	48.316	100.406	43.014	85.252	140.88	104.743	197.588	109.16	25.688	39.612		197.58
	III	43.014	38.779	13.651	18.364	27.846	13.651	17.745	25.688	31.590	24.286	18.364	15.940		
1993	I	85.226	75.981	70.133	76.423	97.532	94.855	136.36			134.67	77.266	79.56		
	II	121.39	73.929	34.715	147.686	64.592	65.606	134.232	112.29		100.40	41.300	34.71		
	III	20.267	23.597	20.267	19.624	22.915	20.267	29.322			27.119	9.017	25.68		
1994	I	89.145	71.297	85.967	83.723	66.917	103.95	204.275	194.608	161.656		109.16	122.8		
	II	48.316	36.320	43.014	52.914	30.071	156.40	226.171	119.829	94.759		67.650	65.60		
	III	28.580	24.286	27.846	24.286	20.267	27.119	43.014	51.981	37.952		30.827	33.13		
1995	I	114.31	68.123	109.99	85.946	112.172	192.40	315.711	365.107	300.872	227.66	209.61	210.0	2311.9	
	II	58.641	31.590	163.55	67.650	82.630	110.66	160.138	209.613	142.569	113.67	85.252	85.25		209.61
	III	32.361	24.286	25.688	28.580	29.322	41.300	82.630	79.323	73.929	68.682	74.996	73.92		
1996	I	115.87	68.123	108.86	85.946	112.172	192.40	315.696	365.107	300.872	227.66	209.61	210.0	2312.3	
	II	58.641	31.590	163.55	67.650	82.630	110.66	159.960	209.613	142.569	113.67	85.252	85.25		209.61

	III	32.361	24.286	25.688	28.580	29.322	41.300	82.630	79.323	73.929	68.682	74.996	73.92		
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**Remark:** I-Monthly Runoff in million m<sup>3</sup>

II- Maximum Discharge in m<sup>3</sup>/sec

III- Minimum Discharge in m<sup>3</sup>/sec

MMD- Maximum means daily discharge in m<sup>3</sup>/sec

TableB2.1 Estimated mean monthly flow of Awash River at diversion site in MCM (50%, 60%, 70% and 80% dependability).

Basin: Awash Station: Nura-era Drainage area : 14173 Sq.km

Flow month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
V <sub>50%</sub>	95.546	84.759	98.597	96.15	94.58	101.78	149.763	198.376	250.708	129.642	97.334	103.754	1538.272
V <sub>60%</sub>	89.610	79.932	92.085	91.18	88.142	93.376	136.729	184.292	219.412	119.882	86.921	93.074	1456.942
V <sub>70%</sub>	83.673	75.106	85.573	86.208	81.703	84.963	123.695	170.208	188.116	110.122	76.507	82.394	1375.612
V <sub>80%</sub>	77.736	70.288	79.056	81.242	75.249	76.551	110.688	156.097	156.820	100.371	66.094	71.695	1294.136

Table B2.2 Mean monthly flow (m<sup>3</sup>/sec)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1976	35.566	40.260	41.418	45.809	49.908	34.475	42.019	61.152	59.667	33.524	19.169	21.220	40.349
1977	24.536	22.190	20.309	28.946	23.274	27.928	46.128	71.518	81.638	51.106	74.682	59.712	44.331
1978	43.026	54.547	53.705	46.445	38.569	46.653	66.174	58.803	52.873	53.494	39.684	49.207	50.265
1979	48.428	46.082	39.324	40.389	42.064	44.815	57.579	76.529	78.534	58.055	49.060	52.142	52.750
1980	37.697	34.595	34.002	30.005	23.747	28.393	41.217	39.444	33.289	33.842	23.142	20.603	31.665
1981	23.180	27.431	36.649	37.572	29.088	40.220	60.740	96.274	180.303	67.076	28.689	35.127	55.196
1982	34.679	37.806	27.994	26.975	34.341	41.222	57.418	77.516	56.998	51.767	26.207	27.061	41.665
1983	29.212	31.053	37.787	35.883	82.575	47.122	62.551	85.536	195.213	56.587	45.746	53.088	63.529
1984	44.563	29.014	27.168	26.311	34.359	34.621	41.337	62.147	64.493	36.259	34.545	34.635	39.121
1985	30.380	29.193	28.021	36.335	35.325	30.847	39.743	101.334	159.598	30.200	26.165	28.039	47.932

1986	35.848	34.619	42.411	38.312	38.845	54.927	84.647	58.619	50.219	37.148	34.730	35.784	45.509
1987	28.949	31.301	37.730	43.689	51.381	37.188	33.941	55.495	49.864	30.377	28.545	29.880	38.195
1988	34.963	32.186	30.229	29.479	17.088	15.921	43.902	58.445	86.117	42.010	22.273	22.611	36.269
1989	23.950	28.459	25.667	35.075	31.531	40.756	65.601	82.457	146.956	46.207	35.103	36.759	49.877
1990	29.153	47.775	43.543	45.128	31.011	32.342	41.349	65.910	124.716	44.875	39.227	27.799	47.736
1991	27.058	34.776	48.492	44.334	42.371	30.455	52.853	62.919	140.510	47.552	47.321	44.242	51.907
1992	61.184	48.503	25.823	25.940	33.090	26.511	34.000	55.027	84.768	34.017	23.664	25.351	39.823
1993	31.824	31.410	26.189	29.484	36.420	36.595	50.921	75.728	97.012	50.291	29.810	29.710	43.783
1994	33.288	29.474	32.101	32.300	24.988	40.105	76.279	72.669	62.367	48.721	42.115	45.884	45.024
1995	42.688	28.162	41.075	33.158	41.887	74.231	117.891	136.336	116.077	85.012	80.871	78.431	72.985
1996	43.271	28.162	40.653	33.158	41.887	74.231	117.885	136.336	116.077	85.012	80.871	78.431	72.998
Mean	35.402	34.619	35.252	35.463	37.321	39.979	58.770	75.723	97.014	48.721	39.601	39.796	48.138
St.dev.	9.293	8.340	8.548	6.769	13.458	14.215	23.827	24.786	46.314	15.596	18.493	17.018	10.908
Cv	0.263	0.241	0.242	0.191	0.361	0.356	0.405	0.327	0.477	0.320	0.467	0.428	0.227
Cs	1.05	1.04	0.26	0.28	1.84	1.20	1.52	1.39	0.70	1.12	1.35	1.11	1.09
K <sub>80%</sub>	-0.847	-0.848	-0.852	-0.852	-0.795	-0.844	-0.823	-0.829	-0.856	-0.854	-0.835	-0.848	-0.849
Q <sub>80%</sub>	27.530	27.546	27.969	29.696	26.623	27.982	39.161	55.176	57.369	35.401	24.159	25.365	38.878
Q <sub>80% trasf</sub>	29.057	29.074	29.520	31.343	28.099	29.533	41.332	58.236	60.550	37.364	25.499	26.772	41.034

Table B2.3. Monthly Minimum Discharge (m<sup>3</sup>/sec)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1976	19.743	21.375	20.823	23.656	18.179	16.683	15.254	39.153	35.437	10.205	10.973	14.339	10.205
1977	12.600	13.457	14.343	17.678	15.259	10.208	24.850	21.940	48.031	23.081	53.299	19.853	10.208
1978	6.078	15.525	8.130	20.358	24.025	23.487	28.486	32.014	37.590	31.416	20.358	34.451	6.078
1979	15.986	20.868	10.795	27.344	27.344	25.664	43.493	56.979	53.299	48.303	30.821	43.493	10.795
1980	24.875	24.875	27.271	19.101	18.441	19.775	24.875	28.939	21.164	18.441	17.161	13.635	13.635
1981	18.441	16.540	21.878	25.660	19.101	20.463	17.161	45.494	101.842	13.093	17.161	19.775	13.093
1982	14.758	13.635	21.164	21.878	22.607	29.794	25.660	47.730	38.153	31.549	17.794	19.775	13.635
1983	20.463	21.878	26.458	21.164	24.875	27.271	31.549	42.257	33.362	27.271	21.878	48.871	20.463
1984	31.291	24.655	24.655	21.965	23.290	28.989	32.078	39.615	35.327	28.242	31.291	29.746	21.965
1985	26.060	24.655	21.965	26.777	27.505	28.989	28.989	46.042	51.944	25.353	21.318	20.680	20.680
1986	24.341	24.655	32.875	32.078	30.514	35.327	49.936	31.291	28.989	29.746	28.989	29.746	24.341
1987	22.623	24.655	23.290	32.078	26.060	26.060	23.290	32.875	27.505	26.777	21.318	26.060	21.318
1988	31.590	25.688	21.575	21.575	9.983	7.203	16.533	20.267	28.580	27.119	15.940	20.267	7.203
1989	21.575	21.575	18.990	17.745	28.580	30.071	46.522	61.589	112.165	18.364	22.242	28.580	17.745
1990	18.990	28.580	29.322	32.361	24.983	26.830	30.071	18.990	72.868	30.827	28.580	22.242	18.990
1991	25.688	25.688	31.590	19.624	19.624	22.915	30.827	30.827	49.223	33.139	36.320	28.580	19.624
1992	43.014	38.779	13.651	18.364	27.846	13.651	17.745	25.688	31.590	24.286	18.364	15.940	13.651
1993	20.267	23.597	20.267	19.624	22.915	20.267	29.322	38.834	34.771	27.119	9.017	25.688	9.017

1994	28.580	24.286	27.846	24.286	20.267	27.119	43.014	51.981	37.952	47.900	30.827	33.139	20.267
1995	32.361	24.286	25.688	28.580	29.322	41.300	82.630	79.323	73.929	68.682	74.996	73.929	24.286
1996	32.361	24.286	25.688	28.580	29.322	41.300	82.630	79.323	73.929	68.682	74.996	73.929	24.286
Mean	23.414	23.026	22.298	23.832	23.335	24.922	34.520	41.483	48.936	31.409	28.745	30.606	29.711
St.dev.	8.194	5.483	6.482	4.861	5.260	8.785	18.674	17.083	24.666	15.342	18.151	16.915	6.441
Cv	0.35	0.24	0.29	0.20	0.23	0.35	0.54	0.41	0.50	0.49	0.63	0.55	0.22
Cs	0.23	0.58	-0.56	0.51	-0.80	-0.06	1.71	0.93	1.39	1.40	1.76	1.73	-0.19
K80%	-0.851	-0.857	-0.805	-0.856	-0.780	-0.840	-0.807	-0.853	-0.833	-0.832	-0.803	-0.805	-0.831
Q80%	16.440	16.391	16.817	16.399	17.022	16.530	16.801	16.424	16.588	16.596	16.834	16.817	16.604
Q80% trasf.	17.352	17.300	17.750	17.309	17.966	17.447	17.733	17.335	17.508	17.516	17.767	17.750	17.525
V80% tras.	46.4686	41.8489	47.534	44.8643	48.1131	45.2229	47.4877	46.4223	45.3799	46.9087	46.0524	47.534	553.837

Table B2.4 Monthly Maximum Discharge m<sup>3</sup>/sec

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MMD
1976	47.172	49.731	79.252	97.563	74.900	53.253	57.834	80.361	104.743	49.731	31.914	39.153	104.743
1977	50.615	32.613	31.242	121.536	43.078	53.269	78.175	132.858	114.728	146.229	225.165	67.761	225.165
1978	64.609	100.390	78.384	55.496	56.979	68.557	82.622	96.734	94.925	110.704	68.557	123.371	123.371
1979	59.230	59.230	50.422	57.726	75.881	64.609	77.546	156.678	98.556	76.712	78.384	74.230	156.678
1980	69.296	42.257	44.400	82.629	28.939	34.290	111.597	82.629	67.898	75.054	26.458	24.105	111.597
1981	29.794	54.813	91.994	76.535	39.156	86.581	165.362	303.199	295.971	180.187	48.871	54.813	303.199
1982	76.535	87.920	50.028	39.156	85.252	62.469	118.277	129.345	100.406	110.661	43.320	43.320	129.345
1983	35.234	67.898	87.920	81.080	364.001	90.626	104.743	161.751	300.780	87.920	59.853	59.853	364.001
1984	63.714	32.875	31.291	30.514	57.142	39.615	62.593	90.960	109.396	44.155	37.870	41.401	109.396
1985	34.500	34.500	37.870	92.316	74.261	37.012	56.082	241.058	254.603	49.936	37.012	39.615	254.603
1986			64.845	46.042	47.969	93.683	232.238	103.538	106.446	57.142	38.738	40.503	232.238
1987	44.155	71.846	68.300	149.761	213.009	95.060	53.993	118.493	89.614	35.327	38.738	33.683	213.009
1988	67.650	35.514	37.133	67.650	27.119	30.071	139.933	168.056	153.688	85.698	27.119	25.688	168.056
1989	28.580	51.981	37.952	57.671	36.320	56.707	98.979	113.679	279.430	106.208	48.316	44.755	279.430
1990	32.361	109.167	122.963	67.650	35.514	55.749	82.630	142.569	221.975	145.971	159.960	34.715	221.975
1991	28.580	51.981	79.323	80.420	58.641	38.779	159.960	201.559	407.466	90.626	73.929	55.749	407.466

1992	87.920	69.719	48.316	100.406	43.014	85.252	140.882	104.743	197.588	109.167	25.688	39.612	197.588
1993	121.391	73.929	34.715	147.686	64.592	65.606	134.232			100.406	41.300	34.715	147.686
1994	48.316	36.320	43.014	52.914	30.071	156.405	226.171	119.829	94.759		67.650	65.606	226.171
1995	58.641	31.590	163.552	67.650	82.630	110.661	160.138	209.613	142.569	113.679	85.252	85.252	209.613
1996	58.641	31.590	163.552	67.650	82.630	110.661	159.960	209.613	142.569	113.679	85.252	85.252	209.613

Table B.2.5. Summary of hydrometric discharge data of awash @ metahara station

Station name: Metahara Basin: Awash Drainage area: 16417 Sq.km

YEAR		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1973	I	1.185	0.835	1.844	0.908	1.115	10.239	47.318	97.875	53.486	14.982	2.080		
1974	I	0.775	0.449		0.579	2.396	19.881	60.552	58.004	64.055	23.586	3.788	1.065	
1975	I	1.066	0.774	0.871	1.520	3.261	5.481	57.141	1.291	1.249	1.291	1.249	1.365	76.559
1976	I	1.291	1.166	1.291	1.249	1.291	1.249			63.045	15.490	1.796	1.291	
1977	I	0.759	0.420	1.196	0.512	0.705	3.259	35.035	67.621	71.784	22.382	1.196	1.023	205.892
1978	I	0.650	0.778	0.484	0.674	0.999	14.424	55.238	73.205	48.889	10.567	1.480	0.887	208.275
1979	I	0.782	0.547	1.046	1.382	2.725	5.548	49.432	40.892	34.447	20.845	4.428	1.140	163.214
1980	I	1.037	1.116	0.818	1.171	0.516	1.949	24.484	50.128	53.450	25.642	19.051	1.488	180.850
1981	I	1.390	0.963	1.394	2.320	3.306	7.475	31.168	47.923	46.051	37.899	8.974	5.181	194.044
1982	I	65.369	52.459	50.966	54.297	72.889	53.352	97.003	198.76	118.12	100.17	52.904	1.764	918.05

1983	I	35.159	35.669	45.034	44.214	132.17	79.551	138.02	206.31	408.82	155.22	105.25	57.095	1442.5
1984	I	100.69	40.102	38.598	27.892	59.11	62.15	75.077	139.04	127.18	54.886	56.124	131.627	912.47
1985	I	39.597	35.289	33.977	57.234	85.712	44.198	31.378	54.508	48.332	34.87	43.049	56.552	564.7
1986	I	73.132	70.915	90.019	74.141	75.342	103.46	183.74	145	86.619	49.479	57.386	51.697	1060.9
1987	I	49.614	42.786	86.783	71.081	50.049	33.537	26.859	93.359	57.876	16.43	14.496	62.365	605.24
1988	I	24.34	16.291	14.54	26.405	4.506	4.772	39.913	101.82	180.82	63.48	13.501	13.429	503.82
1989	I	17.171	24.872	20.308	57.274	34.662	43.003	122.58	144.54	316.72	76.544	52.864	14.07	924.61
1990	I	42.248	111.66	69.825	72.085	48.538	25.358	41.282	58.681	45.757	11.739	47.192	61.898	
1991	I	35.499	50.861	85.225	69.06	68.744	39.858	99.189	158.55	374.86	97.152	99.052	41.722	1219.8
1992	I	132.35	132.73	33.777	50.575	56.236	35.267	56.686	118.19	292.77	85.059	46.476	85.526	1125.6
1993	I	83.729	76.633	48.589	59.52	122.17	100.09	131.74	361.72	543.62	165.39	67.749	57.416	1818.4
1994	I	65.562	52.794	53.016	55.056	58.64	53.728	150.46	123.73	129.75	70.473	44.087	71.913	929.21
1995	I	37.829	51.942	103.17	59.794	44.127	77.858	160.66	187.97	130.09	42.88	41.505	45.412	983.23
1996	I	50.143	39.527	81.997	48.031	51.119	55.644	92.246		521.34	62.846	26.88	40.828	
1997	I	68.584	47.054	70.409	80.519	59.639	59.891	116.99	131.98	47.074	45.38	30.679	58.246	816.45

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1998	I	25.26	25.262	41.682	29.87	24.441	25.653	64.81	578.51	388.91	189.32	53.317	18.913	1466
1999	I	63.857	56.653	71.72	60.273	73.062	99.805	200.15	419	206.88	199.23	86.246	63.277	1600.2
2000	I	91.24	73.963	71.544	70.04	133.19	109.63	105.41	200.82	161.02	161.3	94.403	73.613	1346.2
2001	I	75.969	72.021	72.92	61.151	138.62	67.056	97.91	64.256	55.272	70.703	80.011	66.986	922.87
2002	I	87.557	63.731	73.74	68.402	62.603	68.437	93.783	157.82	93.22	48.126	18.956	83.171	919.55
2003	I	32.424	25.295	33.699	39.865	25.914	7.72	93.861	58.176	52.442	74.123	48.39	22.384	514.29
2004	I	65.305	50.899	68.169	95.635	4.039	40.887	52.401	46.183	44.293	54.279	36.524	1.922	560.54

Table B 2.6 Mean monthly flow data in Mm<sup>3</sup>

Station name: Metahara							Basin: Awash			Drainage area 16417 Sq.KM.			
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1973	65.600	34.390	25.680	21.120	24.550	24.240	67.560	96.970	148.330	72.050	31.330	32.400	644.220
1974	39.680	22.620	47.200	54.450	38.870	104.650	141.030	216.830	309.720	65.510	20.360	66.660	1127.580
1975	100.57	77.350	65.410	58.680	49.010	59.440	148.000	373.820	583.460	110.000	37.410	48.240	1711.390
1976	67.910	57.600	87.700	102.110	139.670	59.470	115.110	213.550	174.170	62.440	33.180	27.170	1140.080
1977	55.980	49.850	45.950	46.690	54.090	56.630	105.120	182.910	216.190	117.900	221.000	145.730	1298.040
1978	105.00	118.94	153.370	92.270	71.700	78.130	179.110	148.660	101.550	123.290	73.350	109.880	1355.250
1979	133.04	99.860	67.340	55.420	66.560	55.540	81.890	152.650	165.930	70.370	57.440	63.120	1069.160
1980	65.910	59.600	52.560	36.450	33.640	42.720	94.610	89.260	56.740	33.810	22.750	28.690	616.740
1981	31.720	38.140	68.150	85.040	43.280	55.100	132.710	234.300	350.360	189.200	65.600	65.000	1358.600
1982	65.369	52.459	50.966	54.297	72.889	53.352	97.003	198.763	118.123	100.165	52.904	1.764	918.054
1983	35.159	35.669	45.034	44.214	132.171	79.551	138.019	206.308	408.819	155.219	105.249	57.095	1442.507
1984	100.68	40.102	38.598	27.892	59.11	62.15	75.077	139.035	127.18	54.886	56.124	131.627	912.468
1985	39.597	35.289	33.977	57.234	85.712	44.198	31.378	54.508	48.332	34.87	43.049	56.552	564.696
1986	73.132	70.915	90.019	74.141	75.342	103.463	183.74	145.002	86.619	49.479	57.386	51.697	1060.935
1987	49.614	42.786	86.783	71.081	50.049	33.537	26.859	93.359	57.876	16.43	14.496	62.365	605.235
1988	24.34	16.291	14.54	26.405	4.506	4.772	39.913	101.824	180.819	63.48	13.501	13.429	503.820

1989	17.171	24.872	20.308	57.274	34.662	43.003	122.577	144.542	316.72	76.544	52.864	14.07	924.607
1990	42.248	111.664	69.825	72.085	48.538	25.358	41.282	58.681	45.757	11.739	47.192	61.898	636.267
1991	35.499	50.861	85.225	69.06	68.744	39.858	99.189	158.548	374.861	97.152	99.052	41.722	1219.771
1992	132.35	132.728	33.777	50.575	56.236	35.267	56.686	118.188	292.774	85.059	46.476	85.526	1125.643
1993	83.729	76.633	48.589	59.52	122.172	100.094	131.738	361.715	543.617	165.394	67.749	57.416	1818.366
1994	65.562	52.794	53.016	55.056	58.64	53.728	150.458	123.733	129.754	70.473	44.087	71.913	929.214
1995	37.829	51.942	103.17	59.794	44.127	77.858	160.658	187.968	130.089	42.88	41.505	45.412	983.232
1996	50.143	39.527	81.997	48.031	51.119	55.644	92.246	159.976	521.342	62.846	26.88	40.828	1230.579
1997	68.584	47.054	70.409	80.519	59.639	59.891	116.992	131.983	47.074	45.38	30.679	58.246	816.450
1998	25.26	25.262	41.682	29.87	24.441	25.653	64.81	578.51	388.911	189.323	53.317	18.913	1465.952
1999	63.857	56.653	71.72	60.273	73.062	99.805	200.148	419.002	206.877	199.232	86.246	63.277	1600.152
2000	91.24	73.963	71.544	70.04	133.193	109.63	105.407	200.82	161.023	161.304	94.403	73.613	1346.180
2001	75.969	72.021	72.92	61.151	138.616	67.056	97.91	64.256	55.272	70.703	80.011	66.986	922.871
Mean	63.54	57.51	61.98	57.96	66.01	58.96	106.80	184.68	218.91	89.56	57.78	57.28	1080.97
St.dev.	30.45	29.04	28.44	19.19	35.76	26.73	45.95	116.73	158.98	52.91	39.86	32.30	350.82
Cv	0.48	0.51	0.46	0.33	0.54	0.45	0.43	0.63	0.73	0.59	0.69	0.56	0.32

