

**TECHNICAL PERFORMANCE EVALUATION AND REDESIGNING
OF MADA BATU SMALL SCALE IRRIGATION SCHEME, WEST
ARSI ZONE OF OROMIA REGION**

MSc THESIS

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**Technical Performance Evaluation and Redesigning of Mada Batu Small
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MASTER OF SCIENCE IN SOIL AND WATER ENGINEERING
(IRRIGATION ENGINEERING)**

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Final approval and acceptance of the Thesis is contingent upon the submission of its final copy to the Council of Graduate Studies (CGS) through the candidate’s school institute of graduate committee (IGC).

DEDICATION

I dedicate this Thesis to my father Ahmed Beftu, my mother Zara Biku and my wife Fatiya Abdella for nursing me with care, affection, love and for their dedicated help in the success of my life.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this Thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this Thesis. Any scholarly matter that is included in the Thesis has been given recognition through citation.

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ACRONYMS AND ABBREVIATIONS

AI	After irrigation
BI	Before irrigation
EC	Ethiopian Calendar
ER	Effective rainfall
ETo	Reference Crop Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field capacity
GDP	Gross Domestic Product
IRg	Gross Irrigation Requirement
IRn	Net Irrigation Requirement
IWMI	International Water Management Institute
MoWR	Ministry of Water Resources
NGOs	Non- Governmental Organizations
NRMD	Natural Resources Management Directorate
PASDEP	Plan for Accelerated and Sustained Development to End Poverty
SINop	Operational Scheme Irrigation Need
SRAC	Southern Regional Aquaculture Center
SSI	Small Scale Irrigation
USDA	United State Department of Agriculture
PWP	Permanent Wilting Point

BIOGRAPHY

The author was born on September, 1986 GC at Gedeb Asasa worede, West-Arsi zone. He attended his elementary at Debara-Bubura, junior at Bucho, secondary at Asasa and preparatory school at Sheshemene. He completed his preparatory school and joined Hawasa University in 2005, graduated with BSc degree in Agricultural Engineering and Mechanization in July 2009. Upon graduation, he was employed by Oromia Agricultural Research Institute under the branch of Jimma Agricultural Mechanization Research Center. Starting from March 1, 2012, he has been serving in Asella Agricultural Engineering Research Center. In September 2014, he joined the School of Graduate Studies of the Haramaya University to pursue his Master of Science studies in the field of Soil and Water Engineering (Irrigation Engineering).

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TECHNICAL PERFORMANCE EVALUATION AND REDESIGNING OF MADA BATU SMALL SCALE IRRIGATION SCHEME, WEST ARSI ZONE OF OROMIA REGION

ABSTRACT

Irrigation enhances agricultural production, improves the food supply and income of rural population in Ethiopia. From this important viewpoint irrigation projects were widely studied, planned and implemented throughout the country. However, little or no attention was given to the monitoring and evaluation of the performance of already established schemes. This study was done during off season of rain in Gedeb Asasa district, West Arsi Zone on Mada Batu Small Scale Irrigation Scheme to characterize the scheme in terms of capacity, dimensions and functionality of reservoir, main and secondary canal, to evaluate the performance of scheme using performance indices such as conveyance efficiency (E_c), application efficiency (E_a), runoff ratio (ROR), deepercolation fraction (DPF), water storage efficiency (E_s), overall efficiency (E_o) and distribution uniformity (DU), along with water productivity and finally identifying problems of the scheme. For this study three farmers' fields were selected each from the upper, middle and lower stream of the irrigation scheme. The scheme has trapezoidal shape of reservoir with a capacity of 2604 m^3 live storage along with trapezoidal shape of main canal with average size of 161, 59, 38.2 cm at the top, bottom and depth respectively and maximum discharge capacity when gate was full opened at off take was 70 l/sec. Most of the secondary canals were not functioning due to some part of canal like water closing gate and division box were damaged. Due to this water being diverted to its own way by farmer from division box reaching to their farms. Parameters like E_c , E_a , ROR, DPF, E_s , E_o and DU were determined and their average values of scheme were found to be 64.77%, 64.54%, 12.10%, 23.29%, 82.47%, 41.47%, and 93.10% respectively. Water productivities (in terms of water use efficiency) was 0.74 kg/m^3 for the upper and middle and 1.61 kg/m^3 for lower irrigation scheme whereas, the productivity (in terms of irrigation use efficiency) had values of 1.34 kg/m^3 for the upper and middle and 3.68 kg/m^3 for lower stream of the

irrigation scheme. The redesign of scheme was needed due to discharge of main canal to command area size not compatible.

1. INTRODUCTION

With steady increase of the global population, the contribution of irrigation towards boosting agricultural production is enormous. Particularly, in some emerging and least developed countries irrigation development and use is a backbone to the extent that it is responsible for the nations' welfare and feeding the vast majority of their population (FAO, 2005). Irrigation is essential in overcoming the rainfall deficit and stabilizing agricultural production especially in arid and semi-arid areas. Reports indicated that one-sixth of the agricultural land in the world is irrigated and provided more than one-third of the global food production (FAO, 1995). In developing countries, up to 85% of the available water is used for agriculture (FAO, 1996). The average rate of irrigation development of the sub-Saharan Africa countries from 1988 to 2000 was 43,600 ha/year. If this rate is continued, then an additional 1 million hectares of land will be brought into irrigable land by the year 2025 (FAO, 2001).

Considering the current Ethiopian situation with growing population pressure in the highland areas and a rapidly declining natural resource base has necessitated irrigated agriculture and in line with this irrigation is given prime attention on the country's development agenda. The irrigation potential of the country is estimated to be about 3.7 million hectares. Of the total potential, only about 20 to 23% of this potential is put under irrigated agriculture (both traditional and modern irrigation systems) (NRMD, 2011).

Small-scale irrigation is defined as irrigation schemes including traditional and modern, which are owned and managed by smallholders where irrigation water is being supplied and used for irrigation purpose from rivers, ponds, lakes, springs and groundwater sources using different water abstraction techniques and supplied to the irrigation fields using different irrigation methods in order to satisfy crop water requirements. It is applied in an integrated manner with improved crop management practices to increase production and productivity of irrigated crops on sustainable basis (NRMD, 2011).

Recent estimates indicate that the total irrigated area under small-scale irrigation in Ethiopia has reached to 853,000 ha during the last implementation period of PASDEP 2009/10 and

the plan set for development of small scale irrigation is 1,850,000 ha, which is planned to be achieved by the end of the five years GTP of 2015 (GTP, 2010).

Developing countries have made huge investments in infrastructure for irrigation in the form of irrigation schemes over the last half century, realizing its importance for food production for the growing population. This investment, together with improved crop production technologies such as use of fertilizers, hybrid varieties, plant protection techniques etc, has enabled many countries to move towards achieving self-sufficiency in food production. Nevertheless there is also a perception that many irrigation schemes do not perform up to expectations or achieve the goals (Gorantiwar and Smout, 2005).

Irrigation is highly expected to play a major role in the realization of Ethiopian food security and poverty alleviation strategy. Irrigation enhances agricultural production and improves the food supply, income of rural population, opening employment opportunities for the poor, supports national economy by producing industrial crops that are used as raw materials for value adding industries and exportable crops. From this important viewpoint irrigation projects are widely studied, planned and implemented throughout the country.

However, little or no attention is given to the monitoring and evaluation of the performance of already established irrigation schemes. Whether traditional or modern, public agency or community managed many of the existing irrigation systems are deteriorating in their physical structures, operation and management. Performance assessment is used to identify the present status of the scheme with respect to the selected indicators and will help to identify 'why the scheme is performing so which in turn imply means of improvement. Of course performance evaluation needs relevant and reliable data which is rarely measured in Ethiopia (Mekonnen and Seleshi, 2007).

Performance evaluation for any irrigation system is essential to assess how far the goals and objectives set forth at the time of project formulation of the system have been achieved. This is a useful tool to provide necessary feedback for improving the systems management by initiating remedial measures (Rani *et al.*, 2011).

Although performance evaluation of irrigated agriculture has gained momentum since late 1980s worldwide such attempt is rarely carried out in Ethiopia (Mekonnen and Seleshi, 2007). Many irrigation schemes do not perform as much as they should, due to considerable

constraints and setback. Identifying the areas in which they fall short of potentials is essential. To this effect, it is important to measure and evaluate their success or failure objectively and identify specific areas that need improvement. Hence, reliable measures of system performance are extremely important for improving efficiency and management decisions.

The Mada Batu small scale scheme is one of small scale irrigation scheme that was designed to serve limited household of the area but as the population near irrigation scheme was increasing, the farmers were extending their farm land out of designed command and since the scheme was serving for more than 39 years, the reservoir capacity was decreasing due to flood from town deposited sediment to reservoir and the main canal was cracked by tree root at different place results water loss. For these reason commands area and water supply of the scheme was not matching even if a water source is good. Because of this, the farmers of the end side of the command area were stopped irrigating. Therefore this study was needed to evaluate this irrigation scheme technically with the following objectives.

Major objective

The aim of this study was to enhance agricultural production and productivity through improving irrigation efficiency of the system.

Specific objective

- To evaluate the technical performance of Mada Batu irrigation scheme and
- To redesign the scheme based on command area

2. LITERATURE REVIEW

2.1 Importance of Irrigation in Agriculture

Irrigation is 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. Even in areas where total seasonal rainfall is adequate on average, it may be poorly distributed during the year and variable from year to year. Where traditional rain-fed farming is a high-risk enterprise, irrigation can help to ensure stable agricultural production (FAO, 1997). The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climactic volatility in any country (IWMI, 2010).

Irrigation in arid areas of the world provides two essential agricultural requirements: (1) a moisture supply for plant growth which also transports essential nutrients; and (2) a flow of water to leach or dilute salts in the soil. Irrigation also benefits croplands through cooling the soil and the atmosphere to create a more favorable environment for plant growth.

A reliable and suitable irrigation water supply can result in vast improvements in agricultural production and assure the economic vitality of the region. Many civilizations have been dependent on irrigated agriculture to provide the basis of their society and enhance the security of their people. Some have estimated that as little as 15-20 percent of the worldwide total cultivated area is irrigated. Judging from irrigated and non-irrigated yields in some areas, this relatively small fraction of agriculture may be contributing as much as 30-40 percent of gross agricultural output.

Irrigated agriculture faces a number of difficult problems in the future. One of the major concerns is the generally poor efficiency with which water resources have been used for irrigation. A relatively safe estimate is that 40 percent or more of the water diverted for irrigation is wasted at the farm level through either deep percolation or surface runoff. Irrigation science in the future will undoubtedly face the problem of maximizing efficiency (FAO, 1989).

Irrigation is generally considered as a means of modernizing the country's agricultural economy and is an important investment for improving the rural income through increase

agricultural production and productivity. It is also central for reducing the ever increasing pressure on land, especially up in the highlands primarily by increasing the productivity of a unit of land and to some extent by bringing new land under cultivation, particularly in the lowlands where population density is relatively lower and uncultivated land is abundantly available. Moreover, irrigation plays an important role in combating the effects of recurrent droughts and sustains production with efficient and effective use of the available resources; namely, water and land in order to primarily alleviate the problem of food insecurity, improve nutritional status of the rural population and in the long-run to achieve the bigger picture of alleviating poverty. It is through irrigation and integrated crop management that sustainable crop production can be ensured (NRMD, 2011).

2.2 Overview of Irrigation Development in Ethiopia

Ethiopia covers a land area of 1.13 million km², of which 99.3 percent is a land area and the remaining 0.7 percent is covered with water bodies of lakes (MoWR, 2002). The agricultural sector is the leading sector in the Ethiopian economy, 47.7 percent of the total GDP, as compared to 13.3 percent from industry and 39 percent from services (World Bank 2005). Though agriculture is the dominant sector, most of Ethiopia's cultivated land is under rainfed agriculture. Due to lack of water storage and large spatial and temporal variations in rainfall, there is not enough water for most farmers to produce more than one crop per year and hence there are frequent crop failures due to dry spells and droughts which have resulted in a chronic food shortage currently facing the country (Seleshi *et al.*, 2007).

Irrigation is practiced in Ethiopia since ancient times producing subsistence food crops. However, modern irrigation systems were started in the 1960s with the objective of producing industrial crops in Awash Valley. Private concessionaires who operated farms for growing commercial crops such as cotton, sugarcane and horticultural crops started the first formal irrigation schemes in the late 1950s in the upper and lower Awash Valley. In the 1960s, irrigated agriculture was expanded in all parts of the Awash Valley and in the Lower Rift Valley. The Awash Valley saw the biggest expansion in view of the water regulation afforded by the construction of the Koka dam and reservoir that regulated flows with benefits of flood control, hydropower and assured irrigation water supply (MCE, 2004).

The irrigation area in year 2002 was 197,000 hectares with a coverage distribution of 38 percent traditional, 20 percent modern communal, 4 percent modern private and 38 percent public schemes (MoWR, 2002). Based on the present indicative information sources, the potential irrigable land is about 3.7 million hectares (NRMD, 2011).

Irrigation is one means by which agricultural production can be increased to meet the growing demands in Ethiopia (Seleshi *et al.*, 2005). According to Robel, 2005 also indicated that one of the best alternatives to consider for reliable and sustainable food security development is expanding irrigation development on various scales, through river diversion, constructing micro dams, water harvesting structures, etc.

Currently, the government is giving more emphasis to the sub-sector by way of enhancing the food security situation in the country. Efforts are being made to involve farmers progressively in various aspects of management of small-scale irrigation systems, starting from planning, implementation and management aspects, particularly, in water distribution and operation and maintenance to improve the performance of irrigated agriculture.

The premise is that well-managed irrigation development is key in helping Ethiopia to overcome major challenges including population pressure; soil and land degradation; high climate variability, and low agricultural productivity. In addition, agricultural water development is crucial to improve smallholder livelihood and income in Ethiopia; since irrigation can help farmers increase their crop production and lengthen their agricultural seasons.

The study estimates that over the next two decades, Ethiopia could irrigate over 5 Mha with existing water sources, contributing around ETB 140 billion per annum to the economy and ensuring food security for up to six million households and 30 million direct beneficiaries (IWMI, 2010).

2.3 Overview of Irrigation in Oromia Region

Oromia is the largest state in terms of both population and land area. It covers a total geographical area of about 355,000 km². The region is characterized by immense geographical diversity consisting of high and rugged contoured mountains dissected by the great East African Rift Valley (Seleshi *et al.*, 2007). Oromia has an estimated total

population of 26,553,000, of which 23,030,000 (86.7 percent) of the population are estimated to be rural inhabitants, while 3,523,000 (3.3 percent) are urban (CSA, 2005).

According to the study conducted by Oromia Economic Study Office (1999), the land suitable for surface irrigation in Oromia is estimated to be 1.7 million hectares of which only 97,185 ha (5.5%) has been developed so far. Out of these developed areas, the share of community irrigations constitute 66,224 ha of which 10,820 ha were developed with the help of regional government, 6588 ha were developed by NGOs and 48,816 ha were developed traditionally. The amount of water used for the purpose of irrigation is only 1.5 % of the total 58 billion cubic meters obtained from mean annual runoff generated in the region and 2.1 billion cubic meters of groundwater. The government organs currently involved with irrigation development in Oromia region include: Oromia Irrigation Development Authority (OIDA), Bureau of Agriculture (BoA), and Bureau of Water. The NGOs and donors are many but some of them are: African Development Bank (AfDB), French Agency for Development (FAD), ADF, ESRDF, European Economic Commission (EEC), IFAD, Japan International Cooperation Agency (JICA) and Oromo Self-help (Seleshi *et al.*, 2007).

2.4 Current Status of Small Scale Irrigation Scheme in Ethiopia

The study estimates that current irrigation schemes cover about 640,000 ha across the country. These irrigation schemes vary widely in size and structure, from micro irrigation (RWH), to river diversion, pumping, and small or large dams, etc.

According to the Ministry of Water Resources sector report, the area under irrigation is only about 197,250 ha (3% of the potential irrigable); of which small-scale irrigation accounts about 85,000 ha (MoWR, 1998).

2.4.1 Review of performance of small scale irrigation in Ethiopia

Small-scale irrigation is dominant in Ethiopia. These schemes play a vital role in improving the livelihoods of the smallholder farmers. However, existing small-scale community managed irrigation schemes face various problems related to operation and maintenance, water management and sustainability. These problems have greatly reduced their benefits and challenged their overall sustainability (Zeleeke, 2015).

The performance evaluation conducted on 26 existing small scale irrigation scheme in south region of country and identified the major frailer and performing below their capacity due to main canal siltation (50%), sedimentation of the headwork (42%), problem of seepage through foundation (4%), main canal seepage (33%), scouring of downstream bank (8%), drying of rivers (12%), damage on impervious and flexible apron(19%), change of river course(12%), damage of under sluices(27%) and damage on CD works(4%). Likewise, some of the planning, institutional & operation problems are lack of adequate community participation, water right conflict among up streamers and down streamers (12%), market outlet problems (8%), proper handing over problem (31%), lack of proper training. During the time of the study, 18 % the irrigation schemes of the region were not operational because of aforementioned and related reasons (Robel, 2005).

Zerihun and Ketema (2006) conducted experiment at Dire Dawa to Evaluate the performance of an improved traditional small-scale irrigation and found major problems in irrigation scheme is water loss in form of deep percolation. The performance evaluation conducted under farmer practice on Ful-tino and Bulline Gero. The capacity of the main canals Ful-tino far below the design capacity, the conveyance efficiency of the canals were poor, the application efficiencies are low particularly in the head end farms, resulting from excessive deep percolation and water distribution was not uniform (Daniel, 2007). The study conducted on Bulline Gero small scale irrigation scheme also show low efficiencies were achieved due to farmers were applying excess amount of water to their fields without considering the crop water requirement of the crop (Shibru, 2007).

2.5 The Need for Performance Evaluation of Irrigation Scheme

Irrigation water can be diverted from a storage reservoir and transported to the field or farm through a system of canals or pipelines, it can be pumped from a reservoir on the farm and transported through a system of farm canals or pipelines; or it might be pumped from a single well or a series of wells through farm canal or pipelines (Terry and Howell, 2002).

Not all water taken from a source (river, well) reaches the root zone of the plants. Part of the water is lost during transport through the canals and in the fields. The remaining part is stored in the root zone and eventually used by the plants. In other words, only part of the water is used efficiently, the rest of the water is lost for the crops on the fields that were to be irrigated. This can be lost by evaporation from the water surface, deep percolation to soil layers underneath the canals, seepage through the bunds of the canals, overtopping the bunds, runoff in the drain and rat holes in the canal bunds (FAO, 1989).

Sener *et al.* (2007) stated that the performance of many irrigation systems is significantly under their potential due to a number of shortcomings, such as poor design, construction and operation and maintenance. In recent years improving irrigation systems performance is more preferable than developing new irrigation areas due to investment in irrigation has failed to produce the expected result in many countries. Moreover water resources are too limited to open new schemes in the region. Therefore improving the performance of the existing schemes seems to be a sustainable and attractive.

According to Clemmens and Molden (2007) two major approaches to performance evaluation are to consider, how well service is being delivered and the outcomes of irrigation in terms of efficiency and productivity of resources use. Gorantiwar and Smout (2005) have summarized performance measures proposed by various researches into allocation type and scheduling types. Allocation types performance measures are those which need to be attained primarily during the allocation of the resources at the planning and operation stages. Productivity and equity are performance measures under allocation type category. Scheduling type performance measures consists of irrigation scheduling, i.e. temporal and spatial distribution of irrigation water to the users. This measures adequacy, reliability, flexibility, efficiency and sustainability. Field evaluation of surface irrigation systems plays a fundamental role to determine the efficiency of the system as it is being used

and to identify management practices and system configurations that can be easily and efficiently implemented to improve the irrigation efficiency (Merriam *et al.*, 1983; FAO, 1989). The field evaluation should at least identify problems such as applying too much or too little water, the poor distribution of infiltrated water over the field, excess tail water runoff or significant deep percolation losses (Zerihun and Ketema, 2006).

To carry out performance evaluation of irrigation schemes, a set of recognized and accepted parameters are required. Among the facts used to judge the performance of an irrigation system or its management, the most common ones are efficiency and uniformity. These parameters have been subdivided and defined in a multitude of ways as well as named in various manners. There is no one single parameter which is sufficient for defining irrigation performance. Ultimately, the measures of performance are whether or not the same promoted production and profitability on the farm.

Abrenethy (1989) defined performance as measured levels of achievement in terms of one or several parameters which are chosen as the indicators of the systems goals. According to James (1988), the performance of a farm irrigation system is determined by the efficiency at which water is diverted, conveyed and applied, and by the adequacy and uniformity of application in each field on the farm. Mishra and Ahmed (1990) also pointed out that irrigation efficiency indicated how efficiently the available water supply was being used, based on the different methods of evaluation. The objective of these efficiency concepts is to show where improvements can be made, which will result in irrigation that is more efficient.

The common efficiency terms used for on farm irrigation system evaluation include application efficiency, uniformity, storage efficiency and adequacy. Recently complementary terms such as runoff ratio, deep percolation ratio and others are being applied (Jurreins *et al.*, 2001).

2.5.1 Irrigation efficiency

Irrigation efficiency E_i is the ratio, usually expressed as percent, of the amount of water used to meet the consumptive use requirement of the crop plus that necessary to maintain a favorable salt balance in the crop root zone to the total volume of water diverted, stored or pumped for irrigation (Michael, 2008).

FAO (1989) and Terry and Howell (2002) define irrigation efficiency in terms of irrigation system performance, uniformity of the water application and response of the crop to irrigate.

Irrigation efficiency is described by several term used to measure how efficiently irrigation water is applied to the field and/or used by crop. High irrigation efficiency translates into lower operation cost, improve environmental benefit and management. Incorrect use of efficient terms can lead to misrepresentation of how well an irrigation system is performing.

According to FAO (1989) and Irmak *et al* (2011), several efficiency terms are used to evaluate irrigation system performance. This includes water conveyance efficiency, water application efficiency, soil water storage efficiency, irrigation efficiency, over all irrigation efficiency and effective irrigation efficiency.

2.5.1.1 Water conveyance efficiency (Ec)

Irrigation water is normally conveyed from a water source to the farm or field through natural drainage ways, constricted earthen or line canals, or pipelines. Many conveyance systems have transmission losses, meaning that water diverted to the farm or field is usually less than the water diverted from the source. Water conveyance efficiency is affected by water losses through evaporation, seepage, transpiration by undesired vegetation and leakage through water control structures in the conveyance system. The loss may be varying from 25 to 60 percent of the water diverted for irrigation. In unlined canal, water ways and channels, water loss is usually heavy and the same is attributed mainly to seepage. Soil permeability, wetting perimeter and depth of water in conveyance structures, depth of water table below the canal bed, time for which water is run, temperature of water and type of material used in construction of the conveyance system are the principal factors influencing the seepage loss. There is often a growth of undesirable vegetation along and in canals and in channel beds and side. The loss through transpiration by this vegetation may sometimes be considerable. Occasionally, animals like rats and rabbits make burrows in channel bunds (Majumdar, 2002). There may be cracks in channel beds and bunds leading to water losses. The water conveyance efficiency is typically defined as the ratio between the irrigation water that reaches a farm or field to that diverted from the water source. It is expressed as (Irmak *et al.*, 2011):

$$E_c = (V_f/V_t) \times 100$$

(2.1)

where E_c = water conveyance efficiency (%)

V_f = volume of irrigation water that reaches the farm or field (M^3)

V_t = volume of irrigation water diverted from the water source (M^3)

The water conveyance efficiency also can be applied to evaluate individual segment of canal or pipelines. Conveyance losses are primarily dependent on the wetted perimeter of the canals and not on the volume of water conveyed. Typically, conveyance losses are much lower for pipelines due to reduced evaporation and seepage losses.

The conveyance efficiency mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals. In large irrigation schemes more water is lost than in small schemes, due to a longer canal system. From canals in sandy soils more water is lost than from canals in heavy clay soils. When canals are lined with bricks, plastic or concrete, only very little water is lost.

According to FAO (1989) state conveyance efficiency of earthen canal for canal length long (> 2000 m) 60%, 70%, 80% , for canal length is Medium (200-2000 m) 70%, 75%, 85% for canal length short is (< 200 m) 80%, 85%, 90% for sand, loam and clay respectively. If it was lined canal conveyance efficiency is 95% through length for three soil type.

2.5.1.2 Water application efficiency (E_a)

Water application efficiency (E_a) provides a general indication of how well an irrigation system performs its primary task of delivering water from the conveyance system to the crop. The objective is to apply the water and store it in the crop root zone to meet the crop water requirement. E_a is expressed as:

$$E_a = (V_s/V_f) \times 100$$

(2.2)

where E_a = water application efficiency (%)

V_s = volume of irrigation water stored in the root zone

V_f = volume of irrigation water delivered to the farm or field

The water or field application efficiency (E_a) mainly depends on the irrigation method and the level of farmer discipline.

Field application efficiency for surface are (border, furrow, basin) are 60%, sprinkler 75% and drip irrigation 90% (FAO, 1989). Lesley (2002) suggested that it could be in the range of 50-80%.

2.5.1.3 Overall irrigation efficiency (E_o)

The overall irrigation efficiency (E_o) represents the efficiency of the entire physical system and operation decision in delivering irrigation water from a water supply source to the target crop. It is calculated by multiplying the efficiencies of water conveyance and water application (FAO, 1989; Irmak *et al.*, 2011).

$$E_o = (E_c \times E_a) \times 100 \quad (2.3)$$

where E_o = overall irrigation efficiency (%)

E_c = water conveyance efficiency (decimal)

E_a = water application efficiency (decimal)

A scheme (overall) irrigation efficiency of 50-60% is good; 40% is reasonable, while a scheme Irrigation efficiency of 20-30% is poor (FAO, 1989)

2.5.1.4 Estimation of water storage efficiency

The water storage efficiency refers to how completely the water needed prior to the irrigation was stored in the root zone during irrigation. Based on the FC, PWP and bulk density of the soils of the selected irrigation fields and the root depth of the crop irrigated, the depth of irrigation water required by the crop was calculated as actual soil moisture depletion level (FAO, 1998).

2.5.1.5 Distribution uniformity coefficient

The distribution uniformity is more commonly used to characterize the irrigation water distribution over the field in surface irrigation systems, but it also can be applied to micro and sprinkler irrigation systems.

The preferred measure of uniformity is the DU which compares the average of the lowest 25% of test can readings to the average of all readings. A DU of 100% would indicate that the application was perfectly even. In practice, this does not happen.

The general form of the distribution uniformity can be given as Howell (2002)

$$D_{up} = 100 (V_p/V_f) \quad (2.4)$$

Where D_{up} = is the distribution uniformity in % for lowest “p” fraction of the field or farm (lowest one-quarter $p = 1/4$)

V_p = is mean application volume lowest one quarter (m^3)

V_f = is the mean application volume (m^3) for whole farm or field.

Values of DU less than 60% are generally considered low and a value of D_{up} greater than 75% is recommended.

2.6 Irrigation Discharge Measurement

2.6.1 Area-velocity method

This method comprises measuring the mean velocity V and the flow area A and computing the discharge Q from the continuity equation. The site which satisfies the requirements such as straightness, stability, uniformity of cross-section is chosen for discharge measurement. A current meter measurement is the summation of the products of the subsection area of the stream cross-section and their respective average velocities. The continuity equation is used as stated (Mushtaq *et al.*, 1997).

$$q = a * v \quad (2.5)$$

$$Q = \quad (2.6)$$

where q = discharge from an individual section

a = individual section area

v = mean velocity of the flow normal to the section

Q = total discharge from the cross- section

The velocity of water in a stream or river may be measured directly with a current meter. The current meter is a small instrument containing a revolutions wheel or vane that turned by the movement of water. It may be suspended by a cable for measurements in deep streams or attached to a rod in shallow stream. The propeller is suspended facing the center of the flow in the stream (or pipe). The propeller is rotated by flow of water. The speed of the propeller (rpm) is proportional to the average velocity of flow in the conduit. Current meter measurement in canal and stream in canal and stream are generally made at metering bridges, at cableways, or at other structures giving convenient access to the stream. The channel at the measuring section should be straight, with a fairly regular cross-section. Structural with pier in the channel are avoided as far as possible.

When a mean velocity of a stream is determined with current meter, the cross section of the flow is divided into a number of sub-areas and separate measurements are made for each sub-area (Michael, 2008).

2.6.1.1 Selecting depth and width of operation

During the measurement, the rod needs to be held in a vertical position and the current meter must be parallel with the flow direction. If the water depth is 75 cm, or more than 75 cm, the two-point method is used. For this case, the propeller or cups are set at a depth of 0.2 and 0.8 of the total depth as measured from the free water surface. Whether the depth of water is less than 75 cm, then the six-tenths method is used. For this case, the depth of observation will be 0.6 of the total depth from the free water surface.

For tertiary channel (watercourses), if the water depth is 45 cm, or more than 45 cm, two point method is used. In this case, the propeller or cup are set at a depth of 0.2 and 0.8 of the total water depth as measured from the free water surface. Where the depth of water is less than 45 cm, then the six-tenth method is used. For this case, the depth of observation will be set at 0.6 of the total depth as measured from the free water surface (Mushtaq *et al.*, 1997).

Measuring cross-section should be subdivided into twenty or more verticals for a relatively smooth channel bed. For an irregular channel bed, more vertical are needed, not only to better define the cross-sectional area of flow, but also because an irregular bed cause more

variation in the velocity distribution. At the same time, verticals do not need to be spaced closer than 0.3 m (Mushtaq *et al.*, 1997).

Discharge carried by any subsection should be up to 10% of the total discharge of the entire section. The width of any subsection should be about 5% of the total width of the river at the site. There should not be any large velocity difference between the adjacent subsections. The discharge variation between adjacent subsections should be 5-10%.

2.6.2 Parshall flume

The Parshall flume is an open channel type of water discharge measuring device that operates with small drop in head. This flume was developed in the 1920s in the USA (R. L. Parshall) and since then large numbers have been used and given satisfactory service at water-treatment plants and irrigation schemes. It consists of a short parallel throat section wall preceded by a uniformly converging section and followed by a uniformly expanding section. The floor is horizontal in the converging section, slopes downwards in the throat, and is inclined upwards in the expansion. The control section, at which the depth is critical, occurs near to the downstream end of the convergence, upstream at the throat. The flume can be used either in the modular or the non-modular mode of operation, so that two head measurements have to be made: the upstream gauging point is in the converging approach section and the downstream gauging point is at the downstream of the parallel throat section.

There are 22 standard designs, covering a range of discharge from 0.1 to 93 m³/s, can be accurately measured with properly sized and constructed/installed Parshall flumes. The discharge ranges of each of the standard sizes overlapping the range of the next size up or down. Parshall flume may be built from wood, concrete, galvanized sheet metal, or other material. Sheet metals have proved very satisfactory, and are portable, have long life, can be re-adjust. Although the basic shape of the flume is the same for all the standard designs they are not scale models of each other, so that the stage-discharge relation for each flume had to be obtained by direct calibration; it is thus essential to construct the flumes to the dimensions specified. For the same reason, the head should be measured at the positions specified. Parshall flume can predict the discharge to within ± 3 percent. Parshall flume is a

self-cleaning device. Sand or silt in the flowing water does not affect its operation or accuracy. Parshall flumes allow reasonably accurate measurements even when partially submerged. The velocity of the approaching stream has very little influence on its operation. Parshall flumes are their ability to provide accurate flow measurement over a wide range of flows with minimum head loss.

Experience has shown that Parshall flumes should not be placed at right angles to flowing streams, such as in turnouts, unless the flow is effectively straightened and uniformly redistributed before it enters the flumes. Surges and waves of any appreciable size should be eliminated. The water should enter the converging section reasonably well distributed across the entrance width, and the flow lines should be essentially parallel to the flume centerlines. Generally it is advantageous to have the measuring flume conveniently near the point of diversion or regulating gate if conditions of operation require frequent recording of discharge. On the other hand the flume should not be placed too near the head gate, as the disturbed water just downstream from the outlet may cause surging and unbalanced flow; it should best be located in a straight section of the channel. To correlate the flow discharge with depth of water passing through the flume, measurement should be taken at height which is located at a distance of 2/3 of measured from the crest (length of the converging section) (Kedir, 1988). For 3" parshall flume following formula were used to calculate discharge:-

$$Q_L = 0.1771 H^{1.55} \quad (2.7)$$

where Q_L is discharge in l/s

H is depth of water in (m)

2.7 Soil Physical Property

The amount of water, air and nutrients available for plant growth is affected by the soil physical properties and turf management practices that include watering, mowing, and aerifying and how much the fields are used. Determining the physical properties of soils will ultimately help to determine how to manage them effectively.

2.7.1 Bulk density

Mass per unit volume of soil comprising the solid and gaseous phase in exclusion of the liquid is termed as bulk density and expressed in g/cm^3 . Bulk density of soil is influenced by soil texture, organic matter content and tillage practices and ranges from 1.1 to 1.3 g/cm^3 in fine texture surface soil and 1.4 to 1.8 g/cm^3 in coarse texture surface soil. It decreases with an increase in looseness of soil and increases with compaction of soil. The bulk density value indicates the extent of pore space in the soil. A low density indicates a high volume of pore space and a high density, a low volume of pore space in soil (Majumdar, 2002)

2.7.2 Soil texture

The texture of soil is based on the size distribution of the constituent particles. In simple terms, the relative percentage of clay, sand, and silt in a soil mass determines its texture. Furthermore, the soil texture determines the water retention capacity of a soil sample. Sand particles have the largest diameter, whereas clay particles have smallest diameter, among the three soil constituent particles.

Common names	Texture	Basic soil textural class
Sandy soils	Course	Sands Loamy sands Sandy loam Loam Silt loam
Loamy soils	Medium	Silt Sandy clay loam Silty clay loam Clay loam Sandy clay
Clayey soils	Fine	Silty clay Clay

Source:- Chandrasekaran *et al.*, 2010

2.7.2 Soil moisture content

The purpose of irrigation is to replenish the water stored in soil that has been extracted by living plants and used by them for their growth. Soils store this irrigation water for future use by the plants. Soils, depending on their texture and structure, can store and release limited quantities of water that varies among different soils. The measurement of soil water is useful in several ways as a guide to irrigation management. The purposes of soil-water measurement are: - (i) to determine the need for irrigation or the right time to irrigate (ii) to measure the amount of water at two separate dates to permit calculation of water consumption by the crop between the dates of measurement (iii) the amount of water the soil is able to store from irrigation and (iv) to detect problems that may exist related to water in the root zone.

Soil moisture measurements should be made in that parts of the soil from which plant roots extract their moisture and according to the moisture extracted pattern of the particular crop. One measurement is made in the upper quarter of the root zone and one or two measurement at lower levels.

Quantity of water can be measured as the weight fraction of water compared to the weight of soil in which it is contained. It may be stated as the grams of water per gram of soil or pounds of water per pound of soil. Most often it is expressed as percent or grams of water per 100 grams of soil for which the symbol P_w is used meaning percentage of water on a weight basis. The soil is not dry when measured but the calculation is based on the dry weight of soil in which the water is contained. The measurement is made by collecting a sample of the soil to be measured from the appropriate depth and location, placing it immediately in a water-tight container so that it will not dry during collection of further samples or transport to a laboratory. The sample is weighed as received in the laboratory and again after drying in an oven for 24 hours at 105°C. It will be calculated as (FAO, 1989, Michael, 2008):

$$\theta_w = \frac{W_w - W_d}{W_d} \times 100 \quad (2.8)$$

where, θ_w = soil water content on dry weight basis, (%)

W_w = weight of the wet soil (g)

W_d = dry weight of the soil (g)

To convert the dry weight soil moisture fraction into volumetric moisture content (θ), the dry weight fraction (θ_w) was multiplied by its respective bulk density (γ_b) and divided by the specific weight of water (γ_w) as follows;

$$\theta = \theta_w \quad (2.9)$$

Soil moisture content is also expressed in terms of equivalent depth mm/m as:

$$\text{Equivalent depth (mm/m)} = 10 \times \theta \quad (2.10)$$

2.7.2.1 Capacity of the soil to store water

Soils hold different amounts of water depending on their texture and structure. The upper limit of water holding capacity is often called “field capacity” (FC) while the lower limit is called the “permanent wilting point” (PWP). For example, following an irrigation event that

saturates the soil, there will be a continuous rapid downward movement (drainage) of some soil water due to the gravitational force. During the drainage process, soil moisture decreases continuously. The velocity of the drainage is related to the hydraulic conductivity of the soil, in other words, drainage is faster for sandy soils compared to clay soils. After some time, the rapid drainage becomes negligible and at that point, the soil moisture content is called “field capacity”. The wilting point is determined when the soil moisture is so low that the plant is not able to absorb water from the soil, and then the plant is permanently wilted and will die if water is not provided. However, most plants undergo substantial water stress well before this point and vegetables likely sustain substantial yield reductions long before reaching the permanent wilting point.

The total amount of water available for plant uptake is the plant available water (AW) which is the difference between FC and PWP. It is often expressed as a percent by volume (volume of water/volume of sample). The “available water holding capacity” (AWHC) is determined by multiplying the AW by the root zone depth where water extraction occurs. Depletion of the water content to PWP adversely impacts plant health and yield. Thus for irrigation purposes, a “maximum allowable depletion” (MAD) or fraction of AWHC representing the plant “readily available water” (RAW) is essentially the operating range of soil water content for irrigation management.

Although water is theoretically available until wilting point, crop water uptake is reduced well before wilting point is reached. Where the soil is sufficiently wet, the soil supplies water fast enough to meet the atmospheric demand of the crop, and water uptake equals E_{Tc} . As the soil water content decreases, water becomes more strongly bound to the soil matrix and is more difficult to extract. When the soil water content drops below a threshold value, soil water can no longer be transported quickly enough towards the roots to respond to the transpiration demand and the crop begins to experience stress.

Readily Available Water (RAW) is similar to the term Management Allowed Depletion (MAD). However, values for MAD are influenced by management and economic factors in addition to the physical factors influencing p . Generally, $MAD < RAW$ where there is risk aversion or uncertainty, and $MAD > RAW$ where plant moisture stress is an intentional part of soil water management (FAO, 1998).

2.7.3 Measuring infiltration rates

Infiltration is the process of entry of water downwards from the air medium, precisely the soil surface, into the soil medium. It occurs when the field is irrigated or when there is rain. The phenomenon is of great practical importance both in irrigated and rain fed farming as the infiltration rate decided the volume of water entering into a soil profile and the volume of run-off over the soil surface during rain (Majumdar, 2002). It is usually measured by the depth in (mm) of the water layer that can enter the soil in one hour. In dry soil, water infiltrates rapidly. This is called the initial infiltration rate. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate. This is called the basic infiltration rate. The infiltration rate depends on soil texture (the size of the soil particles) and soil structure (the arrangement of the soil particles) and is a useful way of categorizing soils from an irrigation point of view. The most common method to measure the infiltration rate is by a field test using a cylinder or ring infiltrometer (FAO, 1990; Majumdar, 2002).

2.8 Crop Water Requirement

2.8.1 Reference crop evapotranspiration

ET_o can be calculated from meteorological data. Several empirical and semi-empirical methods have been developed over the last 50 years to estimate reference crop evapotranspiration from climatic variables. Some of the methods that have been developed are the Blaney-Criddle, Radiation, Modified Penman and Pan Evaporation methods. The different methods catered for users with different data availability and requiring different levels of accuracy. In all four methods the mean climatic data for a 10-day or a 30-day period are used. ET_o is expressed in mm/day, representing the mean daily value for the period under consideration.

The FAO Penman-Monteith method is now the sole recommended method for determining reference crop evapotranspiration (ET_o). This method overcomes the shortcomings of all other previous empirical and semi-empirical methods and provides ET_o values that are more consistent with actual crop water use data in all regions and climates.

$$(2.11)$$

where: - ET_o = reference evapotranspiration (mm/day)

R_n = net radiation at the crop surface (MJ/m^2 per day)

G = soil heat flux density (MJ/m^2 per day)

T = mean daily air temperature at 2 m height ($^{\circ}\text{C}$)

U_2 = wind speed at 2 m height (m/sec)

e_s = saturation vapour pressure (kPa)

e_a = actual vapour pressure (kPa)

$e_s - e_a$ = saturation vapour pressure deficit (kPa)

Δ = slope of saturation vapour pressure curve at temperature T ($\text{kPa}/^{\circ}\text{C}$)

γ = psychometric constant ($\text{kPa}/^{\circ}\text{C}$)

The manual calculation of E_{To} is a long and tedious procedure, and the risk of making arithmetical errors is fairly high. Computer software has been developed to speed up the calculations and make them less tedious to perform.

One such software is the FAO CROPWAT computer programme for estimating E_{To} and crop water requirements (FAO, 2002).

2.8.2 Crop evapotranspiration

The crop evapotranspiration under standard conditions, denoted as E_{Tc} , is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields under optimum soil water conditions and achieving full production under the given climatic conditions. The values of E_{Tc} and CWR (Crop Water Requirements) are identical, whereby E_{Tc} refers to the amount of water lost through evapotranspiration and CWR refers to the amount of water that is needed to compensate for the loss. E_{Tc} can be calculated from climatic data by directly integrating the effect of crop characteristics into E_{To} . Using recognized methods, an estimation of E_{To} is done. Experimentally determined ratios of E_{Tc}/E_{To} , called crop coefficients (K_c), are used to relate E_{Tc} to E_{To} as given in the following equation:

$$E_{Tc} = E_{To} \times K_c \quad (2.12)$$

where: - E_{Tc} = crop evapotranspiration (mm/day)

E_{To} = reference crop evapotranspiration (mm/day)

K_c = crop coefficient

2.8.3 Effective rainfall (ER)

ER means useful or utilizable rainfall. All the rainfall received are not used by the crops because of its erratic nature such as untimeliness, lesser or higher quantity etc. The useful portions of rainfall which is stored in soil and supplied to the crop for its consumptive use is called effective rainfall. The term effective rainfall has been interpreted differently by different specialists. To a canal engineer, the rain which reaches the storage reservoir is the effective portion. To a hydro electrical engineer, the rainfall which is useful for running the turbines that generate electricity is effective. To an agriculturist, the portion of total rainfall that directly satisfies crop water needs and also the surface run off which can be stored and used for crop production is considered as effective rainfall. The rainwater which moves out of the field by surface runoff and deep percolation beyond the root zone of the crop are ineffective rainfall (Chandrasekaran *et al.*, 2010). Effective precipitations was calculated as stated FAO (1986):

$$P_e = 0.8 * P * 25 \text{ if } P > 75 \text{ mm/month} \quad (2.13)$$

$$P_e = 0.6 * P * 10 \text{ if } P < 75 \text{ mm/month} \quad (2.14)$$

where P = rainfall or precipitation (mm/month)

P_e = effective rainfall or effective precipitation (mm/month)

2.8.4 Crop water requirements and irrigation requirements

It is important to make a distinction between crop water requirement (CWR) and irrigation requirement (IR). Whereas crop water requirement refers to the water used by crops for cell construction and transpiration, the irrigation requirement is the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirement. If irrigation is the sole source of water supply for the plant, then the irrigation requirement will be at least equal to the crop water requirement, and is generally greater to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the soil, underground seepage, etc.), then the irrigation requirement can be considerably less than the crop water requirement.

Estimating the crop water and irrigation requirements for a proposed cropping pattern is an essential part of the planning and design of an irrigation system. The irrigation requirement (IR) is one of the principal parameters for the planning, design and operation of irrigation and water resources systems. Detailed knowledge of the IR quantity and its temporal and spatial variability is essential for assessing the adequacy of water resources, for evaluating the need of storage reservoirs and for the determining the capacity of irrigation systems. It is a parameter of prime importance in formulating the policy for optimal allocation of water resources as well as in decision-making in the day-to-day operation and management of irrigation systems.

Incorrect estimation of the IR may lead to serious failures in the system performance and to the waste of valuable water resources. It may result in inadequate control of the soil moisture regime in the root zone; it may cause waterlogging, salinity or leaching of nutrients from the soil. It may lead to the inappropriate capacities of the irrigation network or of storage reservoirs, to low water use efficiency and to a reduction in the irrigated area. Overestimating IR at peak demand may also result in increased development costs (FAO, 2002).

2.8.4.1 Net irrigation requirements

The net irrigation requirement is derived from the field balance equation:

$$IR_n = ET_c - (P_e + G_e + W_b) + LR_{mm} \quad (2.15)$$

where: IR_n = net irrigation requirement (mm)

ET_c = crop evapotranspiration (mm)

P_e = effective dependable rainfall (mm)

G_e = groundwater contribution from water table (mm)

W_b = water stored in the soil at the beginning of each period (mm)

LR_{mm} = leaching requirement (mm)

The Net Irrigation Requirement (IR_n) does not include losses that are occurring in the process of applying the water. IR_n plus losses constitute the Gross Irrigation Requirement (IR_g) (FAO, 2002).

According to Majumdar (2002) net irrigation requirement is the amount of water needed to bring the soil water content just before irrigation in the root zone of field capacity. This may be expressed as,

$$IR_n = \sum_{i=1}^n \left(\frac{FC_i - MB_i}{AS_i} \right) D_i \quad (2.16)$$

where FC_i = field capacity (%w/w) in the i^{th} layer of soil

MB_i = soil water content just before irrigation (% w/w) in the i^{th} layer of soil

AS_i = apparent specific gravity of soil or bulky density of soil (dimensionless)

D_i = depth of the in the i^{th} layer of soil, cm

n = number of the soil layer in crop root zone D

2.8.4.2 Gross irrigation requirements

The gross irrigation requirements account for losses of water incurred during conveyance and application to the field. This is expressed in terms of efficiencies when calculating project gross irrigation requirements from net irrigation requirements, as shown below:

$$IR_g = \frac{IR_n}{E} \quad (2.17)$$

where: IR_g = gross irrigation requirements (mm)

IR_n = net irrigation requirements (mm)

E = overall project efficiency

2.8.4.3 Net Scheme Irrigation Need (SIN_{net})

This is the net irrigation need, not per hectare, but for the whole irrigation area. Therefore the SIN_{net} is no longer expressed in mm/day, but rather as litres per second (l/s).

$$SIN_{net} = IN_{net} \times \text{Scheme Area (l/s)} \quad (2.18)$$

2.8.4.4 Gross Scheme Irrigation Need (SIN_{gross})

This is the irrigation need for the entire area plus the extra water needed to compensate for losses during delivery. The formula is shown below.

$$SIN_{gross} = SIN_{net} \times \text{Scheme area} = (IN_{net} \times 100/e) \times \text{Scheme area (l/s)} \quad (2.19)$$

2.8.4.5 Operational Scheme Irrigation Need (SINop)

This is the actual flow of water which should be delivered to the scheme according to a predetermined irrigation schedule. The total volume of water for the entire irrigation season is the same for SINgross and SINop, but the operational factors make the flow of SINop larger than SINgross. Generally, irrigation is carried out not every hour of every day, but only during specific hours of certain days. Thus, the larger flow of water for SIN is needed to compensate for the times when irrigation water is not being delivered. This timing or scheduling of irrigation is called operational criteria (Top). It was calculated as stated FAO (2002).

$$\text{SINop (l/s)} = \text{SINgross}/\text{Top} \quad (2.20)$$

$$\text{Top} = d/7 \times h/24 \quad (2.21)$$

where: SINop = operational scheme irrigation need

Top = operational criteria

d = number of irrigation days per week

h = number of irrigation hours per day

SINgross = gross scheme irrigation need

2.8.4.6 Scheme Water Supply (SWS)

This is the flow of water that can be withdrawn for irrigation at the water source. For schemes that depend on pumped water, the SWS can never be greater than the capacity of the pump installed. For schemes that do not depend on pumps, the SWS can not exceed the capacity of the intake facility. The scheme water supply is expressed in litres per second. Sometimes, if water flows are large, the supply will be expressed in m³ per second.

2.8.4.7 Irrigation scheduling

Irrigation scheduling is simply applying water to crops at the “right” time and in the “right” amount and it is considered an important best management practice (BMP). Typically, irrigation scheduling often consists of grower judgment or a calendar-based schedule of irrigation events based on previous seasons. Several factors such as plant evaporative demand, soil characteristics and root distribution are taken into account as well, in order to establish proper irrigation scheduling. Theoretically irrigation scheduling consists of irrigating at a low threshold corresponding to a water content at a given MAD and irrigating until the depleted water has been replaced to, but not more than, the FC level; otherwise drainage and/or deep percolation will occur.

2.8.5 CROPWAT model

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. CROPWAT is meant as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rainfed conditions or deficit irrigation (FAO, 2002).

The programme uses monthly climatic data (temperature, relative humidity, wind speed, sunshine hours, and rainfall) for the calculation of reference evapotranspiration. It has also

four different methods to calculate effective rainfall but to be able to do this it requires dependable rainfall as input. Through the input of crop data (growth stages, Kc factors, root zone depth and allowable soil moisture depletion factor), the programme calculates the crop water requirements on a decade (10-day) basis.

CROPWAT uses the sole recommended FAO Penman-Monteith method for estimating ETo. The climatic data required for input into CROPWAT are normally contained in climatic handbooks issued by national meteorological institutions in most countries. Alternatively, different climatic data files on disk saved after earlier sessions or from the CLIMWAT database can be used for the purpose of calculating ETo and effective rainfall.

2.9 Irrigation Productivity

Irrigation productivity is a measure of the economic or biophysical gain from the use of a unit of irrigation water in crop production and is expressed in productive crop units of kg/ha, kg/m³ or \$/m³. As the name portrays, this is the product that is obtained from the irrigated crop to which the diverted water was planned for. Here we just consider our product from irrigation process but do so in ways that capture the whole system of water use and re-use (Machibya *et al.*, 2004).

The water utilization by crop is generally described in terms of water use efficiency (kg/ha, kg/m³ or q/ha) (Michael, 1997). Water use efficiency (*WUE*) and irrigation water use efficiency (*IWUE*) are determined by dividing the yield to seasonal *ET* and total seasonal irrigation water (*IW*) applied (Tanner and Sinclair, 1983).

(2.22)

where WUE is water use efficiency (kg/m³)

Ya is actual yield (kg/m²)

ETc is seasonal crop evapotranspiration (m³/m²)

(2.23)

where $IWUE$ is irrigation water use efficiency (kg/m^3)

Y_a is actual yield (kg/ha)

IW is irrigation water applied (m^3/ha)

2.10 Enlarging the Capacity of an Existing Canal

When extension of an irrigation scheme is considered, information is needed on the capacity of the existing canal network because at least part of this network will have to transport the additional water required to supply the new area. If detailed information is not available on either the current operational carrying capacity of the existing system or on the maximum discharges that could be needed at the time of highest water demand, then this must be collected by surveys in the field. Even if detailed plans are available from when the system was constructed, they need verification in the field in case carrying capacities have been reduced by damage, erosion, siltation or blockage by plant growth in other words, if the system has not been carefully and regularly maintained, then it is the present capacity that is the controlling factor.

If the total required discharges in periods of high water demand are smaller than the maximum allowed discharges in the existing canals that will be involved in the planned extension, it is not necessary to enlarge them, but when the existing canal capacity is limited, it has to be increased to supply the additional water required for the new area. Increasing canal capacity is possible by enlarging the area of the cross-section of the canals concerned.

When the area served by an irrigation canal increases, the discharge required in the canal must also increase. If the capacity of the canal is smaller than the discharge required, then this capacity will have to be increased. There are three ways to increase the capacity of a canal: increase the maximum allowed water depth, increase the bed width and reduce the bed roughness. These may be used singly or in combination. Free board (FB) = 0.20 m for water depths of 0.40 m or less. (Height of the embankment is water depth + 0.20 m); FB = 0.5 x water depth for water depths of 0.40 m or more. (Height of the embankment is 1.5 x water depth, or $h = 1.5 \times h_1$) (FAO, 1993).

2.11 Design of Irrigation Scheme

2.11.1 System design capacity

In order to calculate the design flow of the irrigation system, a number of parameters must be taken into consideration, notably the available moisture, the root zone depth, the allowable moisture depletion, the net peak water requirements, the irrigation frequency and cycle and the irrigation efficiencies (FAO, 2002).

2.11.2 Canal design

The main criterion for a canal design is the need to convey different amounts of water at a fixed level during the irrigation season in such a way that the irrigation requirements are met. The water supply should meet the irrigation requirements and at the same time it should result in the least possible deposition in and/or scouring of the canals. The canal design should preferably be based on capacity, command area, sedimentation and/or erosion and cost (Depeweg and Mendez, 2006). An irrigation canal system consists of canals of different sizes and capacities.

Accordingly, the canals are also classified as: (i) main canal, (ii) branch canal, (iii) major distributary, (iv) minor distributary, and (v) watercourse.

A stable channel is an unlined earth channel : (a) which carries water, (b) the banks and bed of which are not scoured objectionably by moving water, and (c) in which objectionable deposits of sediment do not occur''. This means that over a long period, the bed and banks of a stable channel remain unaltered even if minor deposition and scouring occur in the channel. An irrigation channel can have either a rigid boundary or one consisting of alluvial material. These channels may have to carry either clear water or sediment-laden water.

The design of a stable channel aims at obtaining the values of mean velocity, depth (or hydraulic radius), width and slope of the channel for known values of discharge Q , sediment discharge QT , sediment size d , and the channel roughness characteristics without causing undue silting or scouring of the channel bed.

2.11.3 Design of stable channel

2.11.3.1 Design of lined or non alluvial canal

The design of such channels is based on the Manning's equation combined with the continuity equation. Thus,

$$Q = 1/n * A * R^{2/3} S^{1/2} \quad (2.24)$$

In which, Q = discharge (m^3/s)

A = the area of cross-section of flow (m^2)

R = hydraulic radius (m) which is A/P . Here, P is the wetted perimeter in (m)

n = Manning's coefficient, and

S = slope gradient (m/m).

In practice, the sharp corners in a cross-section are rounded so that these may not become zones of stagnation. Sometimes, the side slopes may also have to be adjusted depending upon the type of bank soil. In India, lined channels carrying discharges less than $55 m^3/s$ are generally of triangular section of the permissible side slope and rounded bottom. A trapezoidal section with rounded corners is adopted for lined channels carrying discharges larger than $55 m^3/s$. The side slopes depend on the properties of the material through which the channel is to pass. To avoid damage to the lining, the maximum velocity in lined channels is restricted to $2.0 m/s$. Thus, the design is based on the concept of a limiting velocity (Asawa, 2008).

2.11.3.2 Design of alluvial channels

An alluvial channel is defined as one transporting water as well as sediment, the sediment transported being of the same nature as that comprising the bed. The stability of a reach of such a channel requires that the sediment inflow into the reach be equal to the sediment outflow. Under such equilibrium condition the bed of the channel neither rises nor falls.

In alluvial channels, both scouring and silting may occur if the channel is not properly designed. The command of an irrigation channel decreases if scouring occurs because the full supply level falls. The discharge capacity is decreased if silting occurs because the cross-section is reduced. Therefore, alluvial channel should be designed such that neither

scouring nor silting occurs. The velocity at which this condition occurs is called critical velocity. Such an alluvial channel is called a stable channel. Various theories have been suggested to study problems of such channels, known as silt theories. The two most common silt theories are: (1) Kennedy's silt theory and (2) Lacey's silt theory. Apart from these two theories, design of stable channels in alluvial soils can be done by the tractive force approach.

Kennedy analyzed data from stable canals of the Upper Bari Doab (in Pakistan) and found that the non-scouring, non-silting velocity, V_O , is related to the depth by the relation,

$$V_O = 0.55D^{0.64} \quad (2.25)$$

where V_O = critical velocity in m/s.

D = water depth

Kennedy also found that the sediment size plays an important role in silt carrying capacity of the channel and introduced the critical velocity ratio m (defined as V/V_O)

$$V = 0.55mD^{0.64} \quad (2.26)$$

where V is the critical velocity in a channel of any other sediment grade and V_O is the critical velocity in a channel of the same sediment grade.

In the design of a stable alluvial channel, in addition to Kennedy's equation, the following two equations are used for the determination of the four unknowns A , V , R and S (if a trapezoidal shape of known side slope is assumed) for known values of Q , m , and n or C .

2.11.3.3 Irrigation Storage Reservoirs

An irrigation reservoir is defined as, an irrigation water storage structure made by constructing a dam, embankment, pit, or tank. Storage reservoirs can provide a consistent supply of irrigation water, provide storage for farms with tail water recovery, and reduce energy costs. These reservoirs are used in cases where pumps are insufficient to provide enough water for irrigation requirements, where water can be taken from streams, surface runoff, or groundwater. In order for a reservoir to be useful, the existing water supply must

be insufficient to meet crop requirements, water is available for storage from some source and a site is available for the reservoir. The reservoir sizing must also take into account crop evapotranspiration requirements, evaporation, seepage, and leaching (NRCS, 2011).

Dams and their associated reservoirs provide many services, including water storage, flow regulation, navigation, hydropower, in-stream and off-stream uses, flood protection, amongst others. However, these artificial lakes and reservoirs evaporate more water than the natural surface water flow before the dam was built, because dams generally increase the surface area of the body of water. This means that more water is exposed to air and direct sunlight, thus increasing evaporation. This “lost” water is referred to as consumed, because it is removed from the system. In some cases, this water consumption can be quite substantial. (FAO, 2015). With calculated ET_o , a coefficient for open water, K_w is then applied to estimate evaporation.

$$E = K_w * ET_o \quad (2.27)$$

where K_w is the coefficient for open water and ET_o is reference ET for short Grass. For open water depths of greater than 5 m, FAO (1998) suggests a K_w value of 0.65 at initial and 1.25 at development of the crop.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

The study was located in Gedeb Asasa district West Arsi zone of the Oromia Region of Ethiopia. Gedeb Asasa is bordered on the south by the Dodola, on the west by Kofele, on the north- west by Kore, and on the north and east by Bekoji. It has a longitude of 39°25'51"E and latitude of 7°21'49"N with an elevation from 2200 to 4180 meters above sea level, mount Kaka is the highest point in the district. A survey of the land in this district shows that 76.9% is arable or cultivable, 17.3% pasture, 0.4% forest, and the remaining 5.4% is considered swampy, mountainous or otherwise unusable. This district is situated on Addis Ababa to Bale road at a distance of 285 km in south west of Addis Ababa and 110 km of south west of Asella town.

The major food crops produced in district are cereals, pulses, oil seeds and others. Among cereals; teff, barley and wheat are the pre-dominant and among pulses horse beans and field peas are grown widely. Other crops include vegetables, fruits, root crops and stimulants are also grown. The mean annual temperature of the district is found between 12-25.3⁰C and annual mean rainfall 995.6 mm.

Mada Batu small-scale irrigation scheme is found in this district at Mada Batu Peasant Associations (PA). The source of water for this scheme is spring water that starts from Asasa town and flows to south of the town and joining Wabeshebele river.

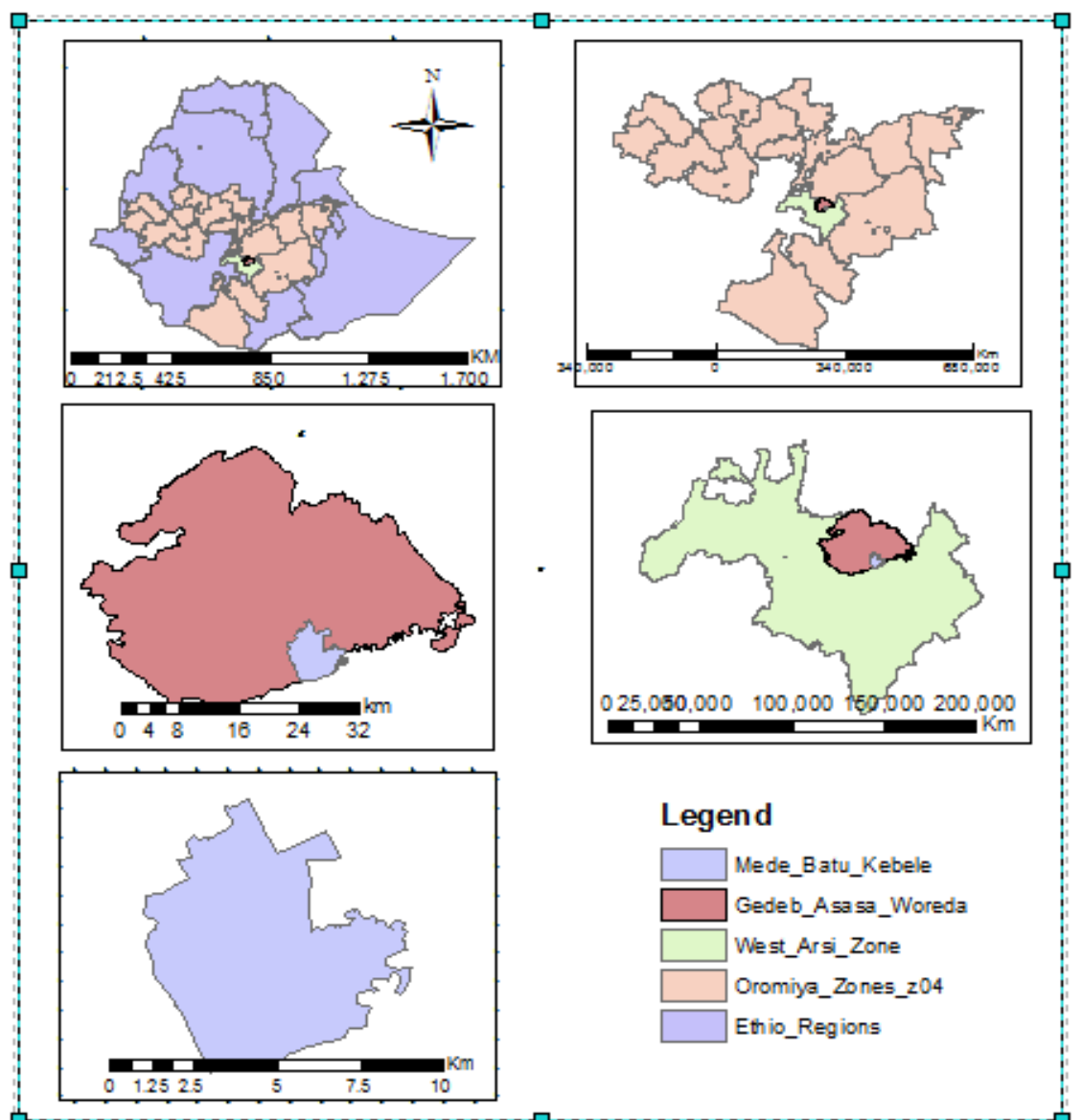


Figure 1. Location map of study area

3.2 Field Layout

This study was conducted at farmers' field and three farmers' fields were selected along the irrigation canal at each from the upper, middle and lower locations of the irrigation scheme with a total of nine plots. The criteria for selection of a plot were location (upstream, middle, and lower), their similarity with irrigation practices, crop grown and willingness of the farmers to collaborate. From each farm plot, soil samples at the depths of 0-30 and 30-60 cm were taken. Total soil samples collected were 54 $(2*3*3)*(3)$ diagonally from farmers fields. These samples were used for analysis of soil physico-chemical properties.

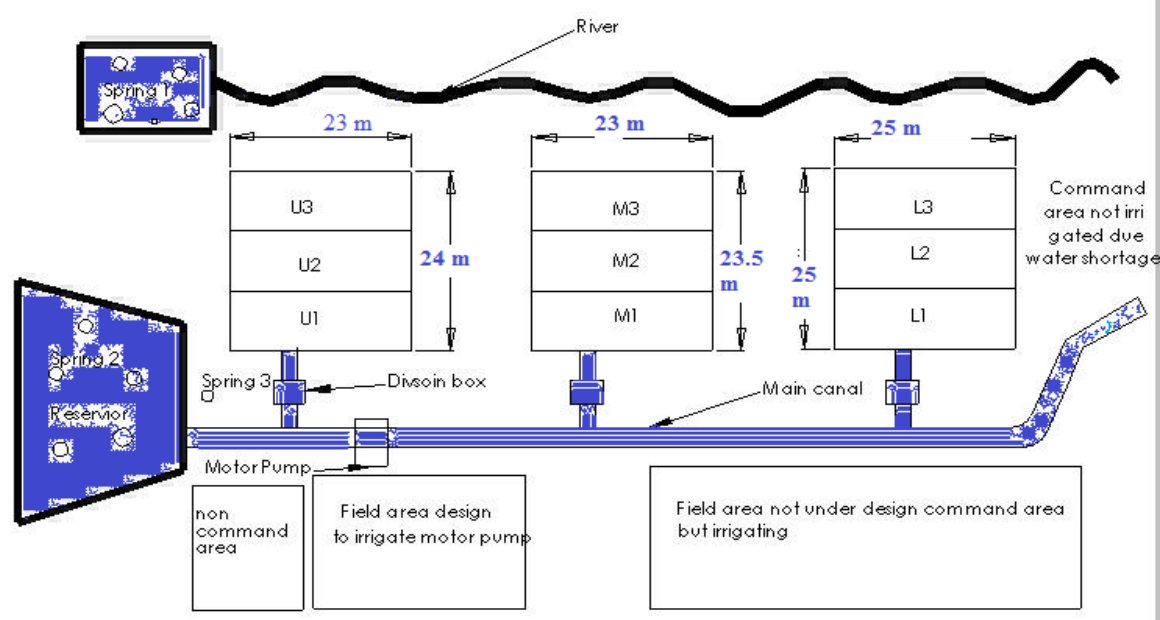


Figure 2. Field layout and location of canal and reservoir

3.3 Agronomic Practices and Selection of the Crop

Most of the irrigated crops grown in the command area of this irrigation scheme are potato, garlic (white onion), carrot and cabbage. Starting three year before the command area was

dominating by garlic crop due to the price cost of the crop is increasing on market from time to time. During the study time three selected farmers were willing to plant the garlic (white onion) for this the crop selected were garlic (white onion) at selected three farms fields.

3.4 Primary and Secondary Data Collection

The study was conducted during the off season of the rain when the crops being cultivated under irrigation. The research work started in December 2015 and continued up until May 30, 2016. During the study period regular visit, observations and the primary and secondary data collection were made to evaluate the scheme. The primary data included characterization of irrigation scheme (reservoir and canal dimension measurements), physico-chemical properties of soil (infiltration rate, soil texture, water holding capacity (FC and PWP), bulk density, Organic matter, pH, electrical conductivity, soil moisture content before and after irrigation), discharge measurement on water flow (at head works, in the main canals, at field inlets), water application practices related to water management on farm and product collection of the selected field were collected.

The secondary data collected were meteorological data from National Metrological Agency and the history of the irrigation scheme from West Arsi Zone and Gedeb Asasa district Offices of Irrigation development Authority.

3.4.1 Characterization of irrigation scheme

The characterization of the scheme was done by field observation and dimensions measurements of scheme reservoir and canals. The reservoir, main and secondary canals were described in terms of their discharge, dimensions and functionality of the scheme elements. Since the reservoir had trapezoidal shape, determination of reservoir capacity was done according to Michael and John (1991) stated for pond capacity calculation of trapezoidal. The top and bottom dimension of dead and live storage were observed and measured. The live storages were measured by closing the night storage at night time and the depth of the water were measured at 24 places at interval of ten meters. The dead storages of the reservoir were also measured releasing water from the reservoir and the depths of dead storage were taken at 10 place of reservoir at interval of ten meters. Finally the live storage and dead storage were calculated by multiplying individual area with average depth of live and dead storage respectively. Then total reservoir storage was

estimated by adding live storage with dead storage. The canal dimension was measured at bottom, top and depth of canal by meters tape at different places.

3.4.2 Soil Physico-chemical properties

3.4.2.1 Bulk density

The bulk densities of the soil were determined from 54 undisturbed soil samples taken with core sampler of 98.13 cm³ at 0-30 and 30-60 cm soil depths. Each wet samples were weighted and dried in an oven at 105⁰C. The dried soil samples were re-weighed. After determining the core volume by measuring the inner diameter and height, the dry bulk density (B_d) was computed as the ratio of oven dry weight of sample (M_s) to known volume of core sampler constant weight. Then, bulk density was determined as stated by (Majumdar, 2002):-

$$B_d = \frac{M_s}{V_t} \quad (3.1)$$

where, B_d = dry soil bulk density (g/cm³)

M_s = dry weight of the soil (g)

V_t = volume of the core sample (cm³)

3.4.2.2 Field capacity and permanent wilting point

Using pressure plate/membrane apparatus the moisture content of the soil at FC and PWP were determined at laboratory by applying pressure at 1/3 and 15 bars, respectively.

3.4.2.3 Soil texture

The texture of the soil was determined using hydrometer method and soil textural classes were determined using the textural triangle of USDA system as described by Sahlemedhin and Taye (2000).

3.4.2.4 Soil moisture determination

To determine the soil moisture content and the adequacy of an irrigation events, the soil moisture content just before and 48 hr after irrigation events were determined using gravimetric method. For this purpose, a total of 432 soil samples were collected at depth of

0-30 and 30-60 cm using soil auger from upper, middle and lower locations of the scheme on four irrigation stage at initial, development, mid and late stage of the crop and the weight of each soil were taken immediately on the farm by digital balance. Then the soil samples were placed in an oven and dried to 105°C to a constant weight. Then the dried soil and the container were again weighed and the weights of water present were determined by subtracting the initial from the final weight. The water contents were determined on such a way on weight and volume basis using equations (2.8) and (2.9). The actual moisture storage or retention (AMS) after irrigation was computed as:

$$\text{AMS (mm/m)} = 10 * [\theta_{AI} (\%) - \theta_{BI} (\%)] \quad (3.2)$$

Total available water (TAW) which is an estimate of the amount of water a crop can use from the soil for the selected fields were computed from the moisture content in volume percent at field capacity and permanent wilting point as:

$$\text{TAW (mm/m)} = 10 * [\theta_{FC} (\%) - \theta_{PWP} (\%)] \quad (3.3)$$

The potential soil moisture storage depth which is equal to the actual allowed depletion depth in the selected fields just before the application of irrigation was computed (Walker and Skoerboe, 1987) as:

$$\text{SMD (mm/m)} = 10 * [\theta_{FC} (\%) - \theta_{BI} (\%)] \quad (3.4)$$

$$\text{SMD or MAD (-)} = \quad (3.5)$$

where MAD = is the actual soil moisture depletion at the time of irrigation

θ_{FC} = soil moisture content in percent volume at FC

θ_{PWP} = soil moisture content in percent volume at PWP and

θ_{BI} = soil moisture before irrigation.

3.4.2.5 Infiltration characterization

To determine the infiltration capacity of the soil, double ring infiltrometer of 30 cm inner diameter and 60 cm outer diameter were used. The two ring inserted 15 cm into the soil to

prevent lateral movement of water then water were filled into the two rings up to edge of the ring then the decrease in head were recorded by 5-10 minute interval up to continually constant reading were obtained.

3.4.2.6 Soil pH and Electrical conductivity

The pH of the soil and electrical conductivity values were measured in laboratory using 1:2.5 soil-water extracts as per the procedure recommended by Sahlemedhin and Taye (2000).

3.4.2.7 Soil organic matter contents

Titration method, which is oxidation under standardized condition with potassium dichromate in sulphuric acid, was followed for organic carbon determination. Finally, conversion of organic carbon to organic matter was, therefore, obtained by multiplying percentage organic carbon by 1.724 (Stanley and Yerima, 1992).

3.4.3 Flow measurement

The flow of water was measured at different point of the scheme. These are: - at the diversion (off take) from the reservoir to canal and at the three field site (upper, middle and lower) of the canal by using area velocity method, the water diverted to the farmers fields measured by installing 3" Parshall flume and water flow out from the fields in the form of runoff were measured by volumetric methods.

3.4.3.1 Velocity measurement

The velocities of flow were measured by mini type propeller current meter at one point depths (0.6 of water depth) of the water flow from surface water. The depth of waters in canal at different location showed in (Appendix Table 2, 3, 4 and 5). To measure flow velocity of water the tail vanes (also known as the fins) of current meter were aligned in reverse direction of water flow. The flow velocity of the water, after current meter is inserted at a point was obtained by starting a stop watch on a click and stopping it on another click after about 45 seconds. Then the average number of revolution and velocity were read from the current meter.

3.4.3.2 Discharge measurement

The discharges of canal at the three entrance of irrigation farm were determined by Area-Velocity method using Mean-Section Method. First the canal cross-section was divided into number of vertical segments or strips (by 5% interval of water width) and average velocities of each segment were measured at depth of 0.6 of water depth. The discharges in each segment were calculated by multiplying the area of the segment with the mean velocity of flow. The total discharge in the canal was computed as the sum of the discharges in various segments as stated in equations (2.5) and (2.6).

To determine the amount of water applied by farmer to the field, three inches (3") Parshall flumes were installed at the entrance of study field. Frequent measurement of water depth were taken at 2/3 distance from the crest (converging section) according to Kedir (1988) stated. Irrigation was continuing until the farmers' thought that enough amount of water is applied to his field. After farmers completed irrigating the study field, the average depth of water passing through the flume was calculated and the discharge was reads from three inches (3") Parshall flumes table. The total discharge entered the field were calculated by multiplying discharge read from table with total time taken to irrigate.

3.5 Technical Performance Indicator Analysis

3.5.1 Water conveyance efficiency

To measure conveyance efficiency, the discharge of water diverted from the reservoir to off take canal and discharge reached at three study sites were measured using Area-Velocity method as indicated in equation (2.5 and 2.6). Then conveyance efficiency was calculated using equation (2.1).

3.5.2 Water application efficiency

The evaluations of the application efficiency were the ratio of stored water to the applied water. The water applied to field was determined using three inches Parshall flumes as stated in section (3.4.3.2) and depth of water stored in the root zone of selected field was determined from the soil moisture content before and two days after irrigation by gravimetric method. The depth of water retained in the soil profile in the root zone was determined using equation given by Mishra and Ahmad (1990):

(3.6)

where Z_r = depths of water stored in the root zone of selected field

θ_{AI} = moisture content of the i th soil compartments after irrigation on oven dry
volume basis (%)

θ_{BI} = moisture content of the i th soil compartments before irrigation on oven dry
volume basis (%)

D_i = thickness of i^{th} soil compartments and

n = number of compartments in the root zone.

The application efficiencies of the fields were calculated using equation (2.2).

3.5.3 Overall irrigation efficiency

Overall irrigation efficiency was determined by using equation (2.3).

3.5.4 Water storage efficiency

The water storage efficiencies were computed by monitoring soil moisture before and after irrigations. After determining the water stored in the root zone of the plants and water needed in the root zone prior to irrigation, the storage efficiency E_r (%) could be computed as:

$$E_r = \frac{W_s}{W_n} \times 100 \quad (3.7)$$

where W_s is depth of water retained in the soil compartments of the root zone computed by equation (3.6) and W_n is water needed in the root zone prior to irrigation and estimated by the following equation:

$$(3.8)$$

where, θ_{FC} and θ_{BI} are soil moisture content at field capacity and moisture content of the soil before irrigation in volume percent, respectively, i , is the number of soil layers and D_i is the depth of soil profile in root zone.

3.5.5 Distribution uniformity coefficient (DUC)

This was computed by arranging moisture content in descending order then finding average of them and least quarter then distribution uniformity were calculated as described in equation (2.4).

3.5.6 Christiansen coefficient of uniformity

The Christiansen Coefficient of Uniformity (C_u) is also widely used in the broader irrigation industry. The C_u value were calculated by determining how much variation (if any) there is for each can reading from the average reading. The total variation from the average was calculated by adding up any difference, whether it is above or below the average value. This total variation was used to determine the non-uniformity of the application.

$$C_u = \frac{(1 - \frac{\sum M_d}{M \times n}) \times 100\%}{M \times n} \quad (3.9)$$

where M = average value of all can readings

$\sum M_d$ = total of variation of each reading from the average

n = number of can readings

A C_u value of 100% would represent a perfectly uniform or even application of water. The industry standard suggests that C_u be greater than 84%. Due to the method of calculation of C_u , it will always have a higher value of uniformity than DU for the same set of readings. It is therefore important to specify which particular uniformity coefficient is being used (Connellan, 2002).

3.5.7 Runoff fraction (ROF)

The farmers of the study are using open tie ridge at the tail of farm and discharge runoff water from the farm to protect their crop from water logging. During the study time the water runoff from the farm were collected in hole of 50 cm diameter and 70 cm depth. Before taking measurement hole is saturated by water before irrigation started then the volume of water collected in hole is measured. Then losses from the irrigation system via runoff from the tail of the field were calculated as:-

$$TWR = \frac{\text{Volume of runoff (m}^3\text{)}}{\text{Volume of water applied to the field (m}^3\text{)}} \quad (3.10)$$

3.5.8 Deep percolation ratio (DPR)

The loss of water through drainage beyond the root zone is reflected in the deep percolation ratio. , DPR, and is defined as:

$$\text{DPR} = \frac{\text{Volume of deep percolation (m}^3\text{)}}{\text{Volume of water applied to the field (m}^3\text{)}} \quad (3.11)$$

Deep percolation fraction(%) can be calculated indirectly from the measured value of application efficiency (E_a) and run off ratio (RR) as given by FAO (1989).

$$\text{DPR} = 100 - E_a - \text{RR} \quad (3.12)$$

High deep percolation losses aggravate water logging and salinity problems, and leach valuable crop nutrients from the root zone. Depending on the chemical nature of the ground water basin, deep percolation can cause a major water quality problem of a regional nature. These losses can return to receiving streams heavily laden with salts and other toxic elements and thereby degrade the quality of water to be used by others.

3.6 Determination of Crop Water and Irrigation Water Requirement

Crop water and irrigation water requirement were determined using CROPWAT computer program. Since the station of the study had only rainfall data and temperature (maximum and minimum), other data like humidity, wind speed and sunshine were taken from nearest Meteorological station (Kulumsa, Zuwayi) from National Meteorological Agency. After the averages of the two stations were calculated, the data were inserted in CROPWAT.

3.7 Yield Data Collection and Estimation of Water Productivity

After attaining the maturity stage of the crop, grain yield of the crop was collected and weighted on weight balance for water productivity analysis. Using the equations (2.22) and (2.23), water use efficiency and irrigation water use efficiency were calculated.

3.8 Comparative Evaluation

The indicators related to irrigation efficiencies and water productivity were examined and compared between the farm lands located at the upper, middle and lower within the scheme using descriptive statistics.

3.9 Statistical Analysis

Data were subjected to analysis in microsoft excel and the measurements of central tendency at the three location (upper, middle and lower) side of irrigation scheme were be determined using descriptive statistics.

3.10 Redesigning the Scheme

3.10.1 Hydrological analysis

Since the spring water was used for irrigation purpose, the continues discharge of flow from the reservoir were measured at different time by Area Velocity Method using current meter at its out let. This continues discharge at different time was averaged and design of reservoir capacity was determined depending on this discharge.

3.10.2 Cropping pattern

The irrigation period is started from November to May and the rest months are cultivated by rain. Generally, cropping pattern for the scheme has been considered based on farmers carry out crop in study area for many years before to determine the crop water need at command area. For this four crop types (potato, garlic, carrot and cabbage) were identified.

3.10.3 Irrigation duty

Amount of irrigated applied to the land continuously for the entire base period of the crop were determined using the CROPWAT.

3.10.4 Soil type and canal type design

Due to costs of contraction, water management and maintenance were simple than other trapezoidal canal were selected. The soil texture type of the irrigation scheme were determined in laboratory and soil textural classes were identified using the textural triangle of USDA system then assumed design parameter were determined depending on soil type

and the redesigning of the water conveyance system was done using manning equation as stated in equation (2.24). Before design started some of parameter like maximum allowable flow velocity (velocity without causing soil erosion), manning's roughness coefficient (n) and channel bed slope were assumed depending on soil type and area condition from standard recommended value.

3.10.5 Cana design procedures of manning formula

Step 1. The discharge (Q), maximum permissible velocity (V), Manning's n, bed slope (S), and side slope (k: 1) are given or have been assumed.

Step 2. Determine the area of cross section from the continuity equation

Step 3. Determine the hydraulic radius, R, from the Manning's formula

Step 4: Determine the wetted perimeter from the relation, $P = A/R$

Step 5: Determine the depth D and bed width B from the values of A and P obtained.

Step 6. Adding free boards

4. RESULTS AND DISCUSSION

4.1 Characterization of the Irrigation Scheme

The Mada Batu irrigation scheme was established by Ethio-Korean government at the end of 1977 EC. During the establishment, the scheme was designed to irrigate 200 ha of land. The source of water for irrigation scheme is spring water that springs by surge flowing from the Kakka Mountain. The spring water starts from Asasa town from two branches. The first branch has high discharge of water, which serves as drinking water for town, nearest kebele of district and neighbors of other district. The second branch is crossed by earth dam to store water for irrigation (Appendix Figure 5). The scheme has one reservoir, which store water at night time and supply day time for irrigation. During rainy season, the farmers use rain water and the reservoir gate is opened and the water is discharged from the reservoir and joined to the first branch. When the rains pass away, the reservoir gate is closed to store water for irrigation purpose.

The farmers' fields were found in the left and right side of the scheme. The left side gets water from main canal by gravity and the right side is irrigated by water lifted from main canal by electrical motor pump installed at upper side of main canal. Due to most of the farm were near main canal water had been distributed to the farm by division boxes constructed near main canal. But some division boxes were not fully functional and they could not divert the required discharge according to the farmer's interest. This had been due to scheme were serving for many years some part of scheme were failing and results high water loss. These consequences the water level in the main canal decreased and did not discharge sufficient amount of water to distributer. For this farmers close one side of division box and the other side wait order until it finishes irrigating. Some farmer at lower side of irrigation scheme also close main canal to lift water level in main canal. The command areas below lower side of the study area were not getting water (Appendix Figure 4).

4.1.1 Reservoir storage

The reservoir storage of the scheme was made from earthen dam. It was having trapezoidal shape and had two off takes gate (Appendix Figure 5). The first one was having regulated discharge from reservoir to the main canal and the second one was used to discharge excess water from the reservoir. During rainy season when there was high rain, flood collected from town over top drainage canal of the road and flooded to the reservoir. This results sediment deposition to the reservoir. This was one of the sources for low level of main canal capacity. Currently the capacity of reservoir has 2604 m³ live storage and 564.3 m³ dead storage. Total reservoir storage was 3168.3 m³ (Table 1).

Table 1. Reservoir dimension and its capacity

Shape	Top width (m)	Bottom width (m)	Average water depth (m)	Area (m ²)	Reservoir length (m)	Volume (m ³)
(1)	(2)	(3)	(4)	(5)=(0.5*(2+3))*4	(6)	(7=5*6)
A1	42.00	28.00	1.55	54.25	48.00	2604.00
A2	28.00	26.00	0.55	14.85	38.00	564.3
Total						3168.3

A1=Reservoir area of live storage A2=Reservoir area of dead storage

4.1.2 Main canal

It was of trapezoidal shape of canal that some parts were lined and others were unlined. The main canal starts from reservoir and convey the water for secondary canal and electrical motor pump. It had different dimensions at deferent place but the average 161 cm top width, 59 cm bottom width and 38.2 cm depth. The maximum discharge capacity of the main canal measured when gate was full opened during the study time at off take, upper, middle and lower stream were 70, 62, 41, 33 l/sec respectively (Appendix Table 2,3,4, and 5). From field observation, the main canal section was grass vegetated, bank was eroded, some part of canal was cracked by trees and no maintenance activities on the main canal were observed during the study time. These are the main reason for water loss along the canal. This canal currently irrigates 330 ha of farmers land even though it was designed to supply for 200 ha.

4.1.3 Secondary canal

Most of the secondary canal of the schemes was found at middle and lower side of study area. Due to the water not reached at lower side of study site and the electrical motor pump was damaged, most of secondary canal was not giving service. Instead of electrical motor pump the farmer of the right side use individual motor pump to irrigate their farm. Upper site were gate water from main canal via division box constructed near main canal. This is due to the farm is near to main canal. Some farms that far from main canal have secondary canals but the farmer not use it due to some part of it like water closing gate and division box were damaged; this secondary canal was found not functioning. Due to non functionality of secondary canal, the farmers divert water to its own way from division box reached their farm.

4.2 Measurement of Physico-Chemical Properties of Soil

4.2.1 Soil texture

From Table 2 the textures of the soil in the three study fields of irrigation scheme fall under loamy soil in all land surface of command area under study. This soil is suitable to grow almost all crops.

Table 2. Laboratory result of soil textural class of Mada Batu irrigation scheme

Soil properties	Soil sampling location								
	US			MS			LS		
Soil depth (cm)	0-30	0-60	Avg	0-30	0-60	Avg	0-30	30-60	Avg
% sand	48	38	43	44	42	43	52	44	48
% silt	28	32	30	32	34	33	26	30	28
% clay	26	30	28	24	24	24	22	26	24
Texture class	Loam	CL	Loam	Loam	Loam	Loam	SCL	Loam	Loam

US=upper stream MS=Middle stream LS=Lower stream SCL=Sandy clay
loam CL= Clay loam

4.2.2 Bulk density

The dry bulk densities of the three study sites were decreasing with depth as seen from Table 3. The average densities of soil at surface and subsurface of irrigation were 1.46, 1.44

g/cm³ respectively which is according to the textural class of the soil from 1.4 to 1.8 g/cm³ as stated by (Majumdar, 2002).

4.2.3 Field capacity and permanent wilting point of the soil

Table 3 shows the average soil moisture content at permanent wilting point at the surface and subsurface as 15.93% and 17.37% respectively and the average value of field capacity as 28.27% and 30.60% at surface and subsurface respectively. The value of total available water (TAW) varied from the lower value of 118.00 mm/m to the high value of 134.00 mm/m.

4.2.4 Soil pH, EC and OM%

From Laboratory investigation of the soil samples collected from the site indicated that the soil organic matter content declined as the depth increased. Organic matter contents were estimated as 3.56% at the surface (0-30 cm) and 2.92% at subsurface (30-60 cm) (Table 3). The weighted average organic matter content of the soil was found to be 3.24%.

The pH and EC of the soil at the experimental area were in the range of neutral and non saline (less than 2 mmhos/cm). This shows that the pH and EC of the area were suitable for crop productions.

Table 3. Soil pH, EC and OM% of irrigation scheme

Soil properties	Soil sampling location					
	US		MS		LS	
Soil depth (cm)	0-30	30-60	0-30	30-60	0-30	30-60
pH	7.491	7.39	6.626	6.827	7.045	7.251
EC mmhos/cm at 25 ⁰ c	0.521	0.429	0.133	0.150	0.204	0.210
% C	1.86	1.76	1.86	1.56	2.47	1.76
OM (%)	3.21	3.04	3.21	2.69	4.26	3.04
Bulk density (g/cm ³)	1.46	1.42	1.45	1.44	1.47	1.45
FC (% Vol)	29.20	32.60	29.00	29.30	26.60	29.90
PWP (%Vol)	17.10	19.20	15.90	15.90	14.80	17.00
TAW (mm/m)	121.00	134.00	131.00	134.00	118.00	129.00

4.2.5 Soil infiltration rate

To determine the infiltration characteristics of the soil, the infiltration rate was measured at three study area (upper, middle and lower) irrigation scheme using double ring infiltrometer as described in Section 3.4.2.5. The basic infiltration rate of the three study area was found to be 12 mm/hr (Appendix Table 1). According to Israelsen and Hansen (1962) the basic infiltration rate of a soil is in the range 10-20 mm/hr, it is classified as a soil with moderate infiltration rate which is the typical characteristics of loam soil. Hence the textural class and infiltration rate were agreed.

4.3 Irrigation Scheme Performance

4.3.1 Conveyance efficiency

An estimate of the amount of water that is lost in the conveyance system is required for effective management decisions and equitable water distribution. Thus it is important to know where the water is going within the conveyance system. The results of the segment and total discharge of main canal at different locations of the canal were calculated using the equation 2.5 and 2.6 as presented in (Appendix Tables 2, 3, 4 and 5) and conveyance efficiency was calculated using equation (2.1). From Table 4 main canal conveyance efficiency were found as 88.6%, 58.6% and 47.1% and water loss at the interval of 400 m, 800 m and 1200 m from off take canal as 7.98 l/s, 28.98 l/s and 37.03 l/s were determined at upper, middle and lower respectively. This shows at interval of 400 m 7.98 l/s, 21 l/s and 8.05 l/s water loss from upper, middle and lower stream respectively. At middle stream there was high loss (21 l/s) of water in canal. This is due to the cracks developed in the canal by tree roots at different places.

Table 4. Conveyance efficiency of main canals at upper, middle and lower stream of the scheme

Position of canal	Canal type	Length from off take (m)	Discharge (l/sec)	Conveyance efficiency (%)	Conveyance loss	
					l/s	l/s /m
Off take	Lined	-	70	-	-	-
Upper	Earthen and lined	400	62	88.6	7.98	0.02
Middle	Earthen and lined	800	41	58.6	28.98	0.04

Lower	Earthen and lined	1200	33	47.1	37.03	0.031
Average				64.77	24.66	0.03

4.3.2 Farmer's fields evaluation

The average areas of the selected farmer's fields were 552, 540.5 and 625 m² for upper, middle and lower fields respectively. The analysis of actual field irrigation performance was done by evaluating data from selected fields.

4.3.2.1 Water application

The water applications of farmer's trains during irrigation event were measured (Appendix Table 7). Average amount of water applied to field per irrigation stage as 89.80, 89.33 and 70.70 mm at upper, middle and lower part of the scheme respectively. This average shows that the water application was decreasing along the stream.

4.3.2.2 Depth of soil moisture depletion or water needs (W_n)

Depth of water needed in the root zone prior to irrigation or soil water depletion was calculated using equation (3.8) as input of soil moisture before irrigation (Appendix Table 6) and field capacity (Table 3) at different soil depth. From Table 5 the average depth of water needed in the root zone prior to irrigation or soil water depletion at different growth stages were 66.98 mm, 62.93 mm and 63.86 mm at the upper, middle and lower of irrigation scheme respectively. The upper stream needed more water than the two sites at different growth stages of crop. This is due to the interval of water holding capacity (FC-PWP) of the upper stream was large.

Table 5. Depth of water needed in the root zone prior to irrigation (soil moisture depletion)

Location	Stage	θ_{BI} at surface v/v %	θ_{BI} at subsurface v/v %	θ_{FC} at surface v/v %	θ_{FC} at subsurface v/v %	W_n at surface in (mm)	W_n at sab-surf ace (mm)	Summ of W_n (mm)
Upper	Initial	18.70	20.30	29.20	32.60	31.50	36.90	68.40
	Dev.	19.20	20.20	29.20	32.60	30.00	37.20	67.20
	Mid	18.60	21.10	29.20	32.60	31.80	34.50	66.30
	Late	18.20	21.60	29.20	32.60	33.00	33.00	66.00
	Average	18.68	20.80	29.20	32.60	31.58	35.40	66.98
Middle	Initial	18.00	18.40	29.00	29.30	33.00	32.70	65.70
	Dev.	19.80	18.20	29.00	29.30	27.60	33.30	60.90
	Mid	19.20	19.50	29.00	29.30	29.40	29.40	58.80
	Late	17.40	18.80	29.00	29.30	34.80	31.50	66.30
	Average	18.60	18.73	29.00	29.30	31.20	31.73	62.93
Lower	Initial	16.40	19.00	26.60	29.90	30.60	32.70	63.30
	Dev.	17.20	19.10	26.60	29.90	28.20	32.40	60.60
	Mid	15.50	18.90	26.60	29.90	33.30	33.00	66.30
	Late	16.10	18.65	26.60	29.90	31.50	33.75	65.25
	Average	16.30	18.91	26.60	29.90	30.90	32.96	63.86

θ_{BI} =Soil moisture before irrigation θ_{FC} =Soil moisture at field capacity W_n =Depth of water needed in the root zone prior to irrigation

4.3.2.3 Farmers field soil moisture content

Table 6 shows summary of average Soil moisture be different after and before irrigations as indicated in Appendix Table 6 at different stages of the crop growth. Using equation (3.7) the depth of water stored at root zone of the crop was calculated. From this table, the average water stored at root zone of the crop decreased from the upper stream to the lower stream of the irrigation scheme. The average water stored at crop root zone at upper, middle and lower of irrigation scheme as 55.71, 53.40 and 50.64 respectively. This shows that in upper stream of irrigation there is high water storage at root zone of the crop than other two streams. This may be due to high amount of water applied to the upper streams than middle and lower streams.

Table 6. Average moisture content of soil at different stage of the crop growth

Location	Stage	Soil Moisture Diff. at surface and subsurface		Soil moisture stored at stored at (0-30 cm) in (mm)	Soil moisture stored at (30-60 cm) in (mm)	Soil moisture stored at crop root zone in (mm)
		0-30	30-60			
		v/v%	v/v %			
Upper	Initial	8.10	9.80	24.30	29.40	53.70
	Dev.	9.30	9.70	27.90	29.10	57.00
	Mid	9.30	9.90	27.90	29.70	57.60
	Late	9.78	8.40	29.34	25.20	54.54
	Average	9.12	9.45	27.36	28.35	55.71
Middle	Initial	8.80	9.10	26.40	27.30	53.70
	Dev.	7.50	8.70	22.50	26.10	48.60
	Mid	9.80	8.60	29.40	25.80	55.20
	Late	9.50	9.20	28.50	27.60	56.10
	Average	8.90	8.90	26.70	26.70	53.40
Lower	Initial	8.90	8.80	26.70	26.40	53.10
	Dev.	7.80	7.70	23.40	23.10	46.50
	Mid	9.40	8.40	28.20	25.20	53.40
	Late	9.30	7.22	27.90	21.66	49.56
	Average	8.85	8.03	26.55	24.09	50.64

4.3.2.4 Application efficiency

Table 7 shows the application efficiency of irrigation scheme calculated using equation (2.2) from depth of water stored to crop root zone (Table 6) divided by depth of water applied to field (Appendix Table 7). The average application efficiency of the three fields were 62.08%, 59.78%, 71.76% at upper, middle and lower respectively. The water application efficiency of lower side of scheme was greater than the two even though the amount of water application was lower than the two fields. This is due to the farmer at lower side of study site who properly used water and applied to field without more loss. The three application efficiency fall in the interval of recommendation for surface irrigation 50-80% as stated by Lesley (2002).

Table 7. Application efficiency of irrigation scheme

Location	Stage	Water applied to field (mm)	Water stored at root zone(mm)	Field application efficiency
Upper	Initial	90.53	53.70	59.32
	Development	91.78	57.00	62.11
	Mid	92.61	57.60	62.20
	Late	84.29	54.54	64.71
	Average	89.80	55.71	62.08
Middle	Initial	91.60	53.70	58.62
	Development	86.58	48.60	56.13
	Mid	86.66	55.20	63.70
	Late	92.46	56.10	60.67
	Average	89.33	53.40	59.78
Lower	Initial	68.01	53.10	78.08
	Development	68.16	46.50	68.22
	Mid	78.25	53.40	68.24
	Late	68.37	49.56	72.49
	Average	70.70	50.64	71.76

4.3.2.5 Runoff fraction (ROR)

Runoff percentage was calculated after collecting water at the tail of the field. From Table 8 below the average runoff of the three fields were very close to each other. The average runoffs registered at upper, middle and lower were 12.55%, 13.13% and 10.82% respectively.

4.3.2.6 Deep percolation ratio (DPR)

Using equation 3.11 and 3.12 deep percolation percentage was calculated. The deep percolation percentage was 25.37 %, 27.09 % and 17.42 % for upper, middle and lower of irrigation scheme respectively (Table 8). From this result the high deep percolation ratio was observed at the middle and upper stream because water management was poor. The average percentage of water loss on the farm (deep percolation + runoff) was 37.92%, 40.22% and 28.24% at upper, middle and lower of irrigation scheme respectively. The average loss of irrigation scheme was relatively safe (35.46%).

Table 8. Runoff and Deep percolation percentage of irrigation scheme at different stage of the crops

Location	Stage	Water applied to field (mm)	Water stored at root zone(mm)	Runoff (mm)	Deep percolate water (mm)	Application efficiency (%)	Runoff (%)	Deep percolation (%)
Upper	Initial	90.53	53.70	11.49	25.34	59.32	12.69	27.99
	Dev.	91.78	57.00	9.99	24.79	62.11	10.89	27.00
	Mid	92.61	57.60	9.09	25.92	62.20	9.82	27.98
	Late	84.29	54.54	14.16	15.59	64.71	16.80	18.49
	Average	89.80	55.71	11.18	22.91	62.08	12.55	25.37
Middle	Initial	91.60	53.70	8.81	29.09	58.62	9.62	31.76
	Dev.	86.58	48.60	5.88	32.10	56.13	6.79	37.08
	Mid	86.66	55.20	5.48	25.98	63.70	6.32	29.98
	Late	92.46	56.10	27.55	8.81	60.67	29.80	9.53
	Average	89.33	53.40	11.93	23.99	59.78	13.13	27.09
Lower	Initial	68.01	53.10	4.84	10.07	78.08	7.12	14.80
	Dev.	68.16	46.50	9.27	12.39	68.22	13.60	18.18
	Mid	78.25	53.40	3.88	20.97	68.24	4.96	26.80
	Late	68.37	49.56	12.04	6.77	72.49	17.61	9.90
	Average	70.70	50.64	7.51	12.55	71.76	10.62	17.42

4.3.2.7 Over all irrigation efficiency

The overall efficiency of the scheme was calculated using equation (2.3) and indicated in Table 9. This efficiency was 55.18%, 35.4%, and 33.84 at upper, middle and lower stream of irrigation scheme respectively. The overall average was 41.47% which is reasonable. According to FAO (1989) overall scheme efficiency around of 40% is reasonable.

Table 9. Overall application efficiency of irrigation scheme

Location	Conveyance efficiency	Application efficiency	Overall efficiency (%)
----------	-----------------------	------------------------	------------------------

Upper	0.89	0.62	55.18
Middle	0.59	0.60	35.4
Lower	0.47	0.72	33.84
Average			41.47

4.4.2.8 Water storage efficiency

Table 10 show water storage efficiency of irrigation scheme. Water stored efficiency was found as less than 100% due to the water applied was lost in form of deep percolation and runoff. So upper and middle stream was little less than 100% than the lower stream.

Table 10. Water storage efficiency of irrigation scheme

Location	Water stored at root zone in (mm)	Water needed at root zone (Wn) in (mm)	Water storage efficiency (%)
Upper	55.71	66.98	83
Middle	53.40	62.93	85
Lower	50.64	63.86	79
Average			82.47

4.3.2.9 Distribution Uniformity

From Table 11, DU of the three locations of the irrigation scheme were 96.39%, 91.01% and 91.82% at the upper, middle and lower respectively. According to Irmak *et al.* (2011) DU less than 60% low and DU greater than 75% recommended. So the DU of the three irrigation schemes was greater than 75% so it is recommended.

Table 11. Distribution uniformity

Location	Soil moisture stored in root zone in descending order	Average	Least quarter	DU in %
Upper	57.60	55.71	53.70	96.39
	57.00			
	54.54			
	53.70			
Middle	56.10	53.40	48.60	91.01
	55.20			
	53.70			
	48.60			
Lower	53.40	50.64	46.50	91.82
	53.10			
	49.56			
	46.50			
Average				93.10

4.4 Water Productivity

The crop water requirement of Garlic was determined using CROPWAT. The seasonal crop water requirement and irrigation requirement of garlic crop were 649.6 mm and 365.6 mm respectively (Appendix Table 11).

Using seasonal water requirement (ET_c) of garlic crop (649.6 mm), irrigation water use and product collected from the three study area water productivity and irrigation water productivity were calculated using equation 2.22 and 2.23 section 2.9. The water productivity of the upper and middle was the same but water productivity at the lower stream was greater than the two study fields.

Table 12. Water productivity of garlic crop

Field location	Area (m ²)	ET _c (mm/season)	Volume (m ³)	Yield (kuntal)	Yield (kg)	Water productivity (kg/m ³)
Upper	552	649.6	358.8	2.65	265	0.74
Middle	541	649.6	351.65	2.59	259	0.74
Lower	625	649.6	406.25	2.95	650	1.61

From Table 13, the irrigation water use efficiency of the upper and middle was the same but the lower irrigation water use efficiency was greater than the two study fields.

Table 13. Irrigation water use efficiency of garlic crop

Field Location	Area (m ²)	Depth of water applied (mm)	Volume Applied (m ³)	Yield (kg)	IWUE (kg/m ³)
Upper	552	359.21	198.28	265	1.34
Middle	541	357.3	193.30	259	1.34
Lower	625	282.79	176.74	650	3.68

4.5 Comparative Evaluation

From Table 14, conveyance loss at middle stream was high since of canal cracked by tree roots. The water application efficiency at lower side was larger due to on farm water loss was low and water management practice was good. Storage efficiency at lower stream was low as applied water less than require water depth and distribution uniformity at upper stream is large since water application is large. The overall efficiency at middle and lower was low because canal water loss was high. Water productivity and Irrigation water use efficiency at lower side of stream was larger than other two locations of the scheme because of yield gain from water consumption were good.

Table 14. Efficiency of irrigation scheme at deferent location

Efficiency	Location		
	Upper	Middle	Lower
Conveyance loss at 400 interval (l/s)	7.98	21	8.05
Application efficiency (%)	62.08	59.78	71.76
On farm water loss (Run off and Deep percolation) in (%)	37.92	40.22	28.04
Water storage efficiency	83.58	84.13	79.69
Distribution uniformity	96.39	91.01	91.82
Overall efficiency	55.18	35.4	33.84
Water productivity (kg/m ³)	0.74	0.74	1.61
Irrigation water use efficiency (IWUE) (kg/m ³)	1.34	1.34	3.68

4.6 Redesigning the Scheme

The redesign of the scheme is needed due to the command area and water supply of the scheme was not matching. According to Gedeb Asasa Irrigation Development Authority secondary data information, the scheme was designed to irrigate 200 ha of land but currently farmers expanded the farm by taking water from the canal by motor pump and increased the command area to 330 ha. Since the scheme was serving for more than 39

years, the reservoir capacity was decreasing due to flood from town deposited sediment to reservoir. It can only take eleven hour to fill the reservoir. For these two reasons (increasing command area and decreasing reservoir capacity), the tail of scheme (below lower side of study area) about 55 ha of land of command area was not getting water. Totally the command suitable for irrigation was 385 when the canal water supply is modified. Using this problem as a base line, the need of redesign of the scheme was identified.

4.6.1 Scheme water requirement

The CROPWAT computer outputs showing, the scheme irrigation requirements of four crops (potato, garlic, carrot and cabbage) highly dominating command area were shown in Table 15. This table shows the output summary of Appendix Table 18 of gross scheme irrigation requirement of command area crops. From this table the highest gross scheme water requirement for four crops pattern was observed in February month which was 261.8 l/s. So this is worst peak discharge which determines the designs of canal.

Table 15. The four crop patterns in study area

Crop type	Irrigation requirement	Dec	Jan	Feb	Mar	Apr	May
	Irr.req. for actual area (l/s/h)	0.15	0.29	0.41	0.35	0.08	0.02
Crop pattern	Gross Irr.req. for actual area (l/s/h) for surface (60% eff.)	0.25	0.48	0.68	0.58	0.13	0.03
	Gross Irrig. Req. for 385 ha(l/s)	96.25	184.80	261.80	223.30	50.05	11.55

4.6.2 Operational Scheme Irrigation Need (SINop)

From Appendix Table 18 or Table 15 the highest gross irrigation requirement for 385 ha were 261.8 which to flow for 24 hour in scheme but most of working time is 12 hour per day. The calculated SINop for 12 hour was 523.6 l/s. So this was the design discharge of main canal for command area.

4.6.3 Reservoir capacity determination

The reservoir capacity was determined depending on water need for the command area and continuous flow of spring water from the reservoir. The average continuous flow of water during study time measurement taken at different time from reservoir (spring water discharge measured after reservoir gate opened and constant water flow reached from reservoir) was 50 l/s but the canal must supply a discharge of 523.6 l/s for 12 hour. The current capacity of reservoir as 2604 m³ was measured however the command areas need as 20,476.8 m³ additional water to continue flow. Therefore 20,476.8 m³ is the redesign capacity of reservoir (Appendix Table 25).

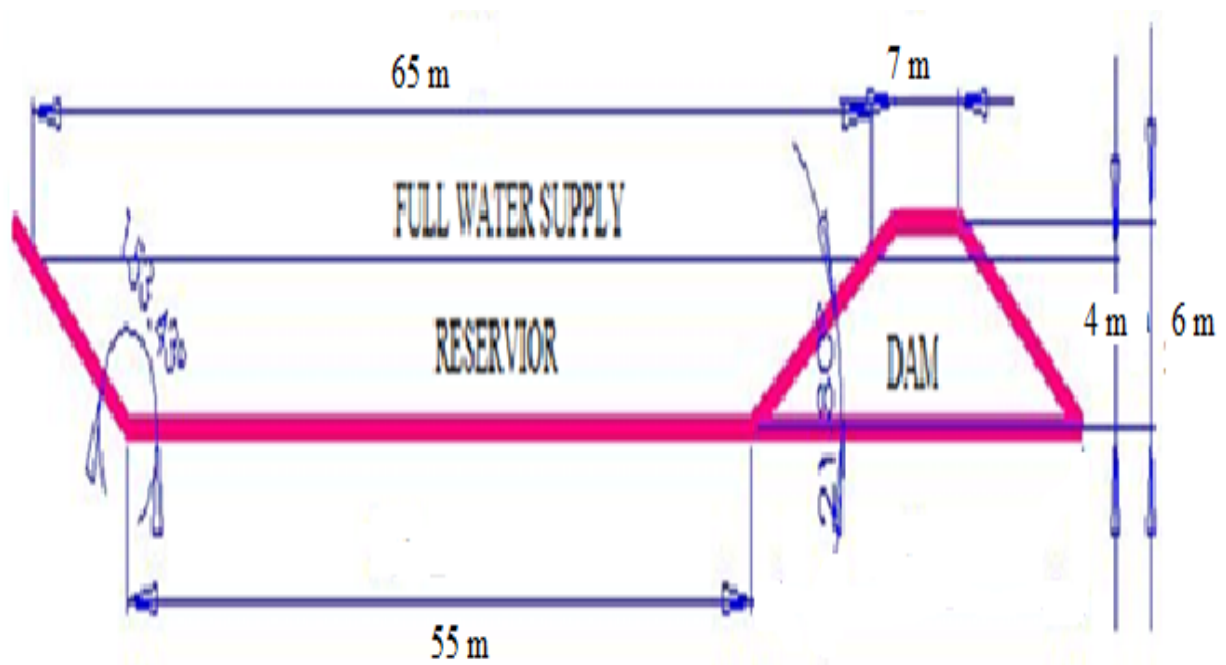


Figure 3. Redesigned reservoir dimension

4.6.4 Distribution structure design

Since soil of the irrigation scheme was loam, safe side slopes are taken as 1.5:1, Manning's coefficient of 0.02 were assumed and design discharge of $0.524 \text{ m}^3/\text{s}$ was calculated. The design procedure is listed in section 3.10.5 using Manning's equation the distribution structure of main, secondary and tertiary canals were iterated.

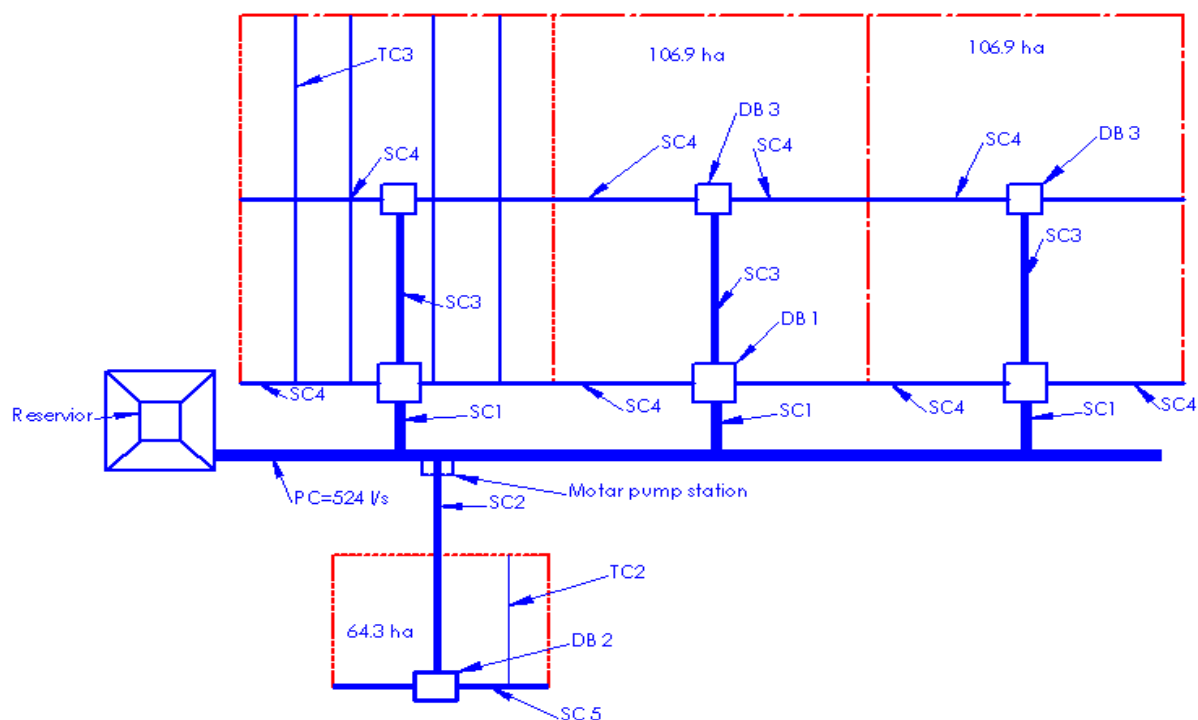


Figure 4. Distribution structure of scheme and command area

4.6.4.1 Main canal

The main canal of scheme was started from reservoir and discharges $0.524 \text{ m}^3/\text{s}$ to command area. The dimensions of the canal iteration were done and it width as 74 cm and depth of 60 cm (Appendix Table 19).

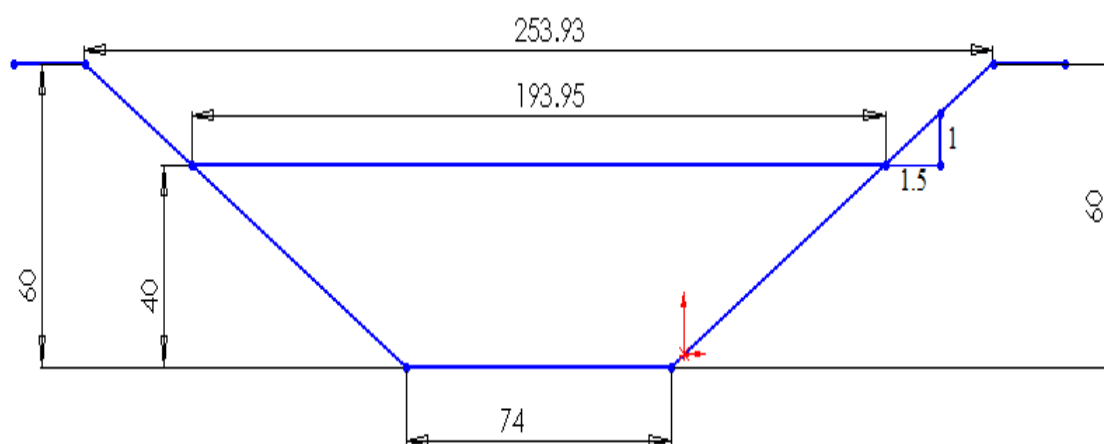


Figure 5. Redesigned main canal dimension in centimeter

4.6.4.2 Secondary canal

Table 16 is showing summary of discharge and dimension of secondary and tertiary canal from Appendix Table (Appendix Table, 20 - 24). From this table secondary canal 1 (SC1) off take 0.146 m³/s of discharge from main canal to division box and have 0.39 m of canal depth and 0.5 m width. Secondary canal 2 off take 0.087 m³/s discharges from motor pump to division box 2 that distribute to secondary canal 5 (Figure 4) which have capacity of 0.044 m³/s and canal depth of 0.26 m and width of 0.28 m. The secondary canal 3, 4 and 5 also discharges 0.073, 0.036 and 0.044 m³/s of water and have canal width of 0.36, 0.26, 0.28 m and canal depth of 0.29, 0.25 and 0.26 m respectively.

4.6.4.3 Tertiary canal

The tertiary canal (TC) also distributes 0.018 m³/s of discharge from secondary canal 4 and 5 (SC2 and SC5) to farm and have 0.23 m canal width and 0.16 m canal depth.

Table 16. Canals dimensions

Canal type	Water depth in (m)	Width in (m)	D/B ratio	Free board in (m)	Total canal depth (m)	Discharge (m ³ /s)
MC	0.40	0.74	0.54	0.20	0.60	0.524
SC1	0.24	0.50	0.48	0.15	0.39	0.146
SC2	-	-		-	-	0.087
SC3	0.19	0.36	0.53	0.10	0.29	0.073
SC4	0.15	0.26	0.58	0.10	0.25	0.036
SC5	0.16	0.28	0.57	0.10	0.26	0.044
TC1	0.11	0.23	0.48	0.05	0.16	0.018

MC= Main canal, SC= Secondary canal and TC= Tertiary canal

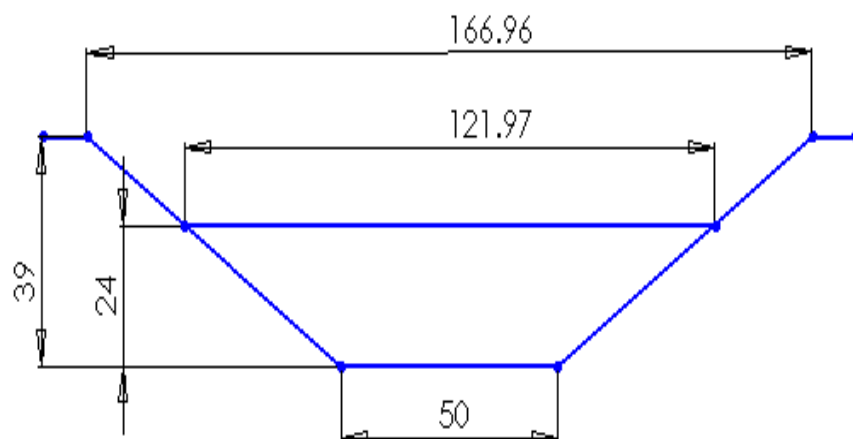


Figure 6. Secondary canal 1 (SC1) dimension in centimeter

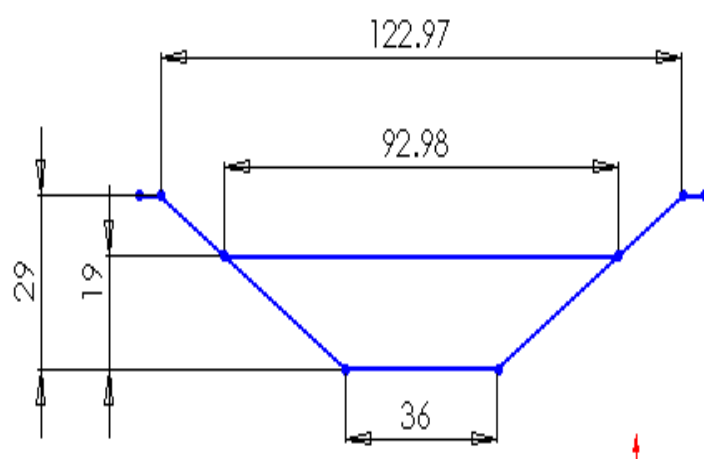


Figure 7. Secondary canal 3 (SC3) dimension in centimeter

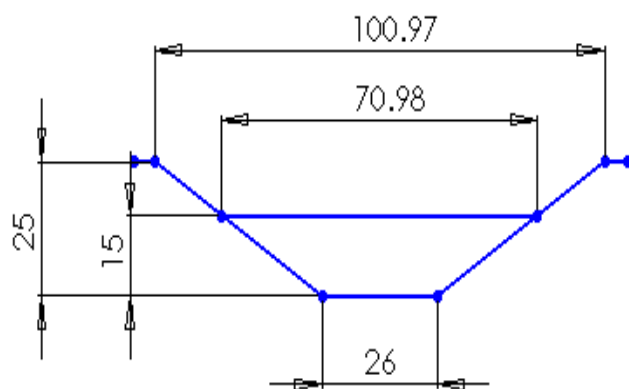


Figure 8. Secondary canal 4 (SC4) dimension in centimeter

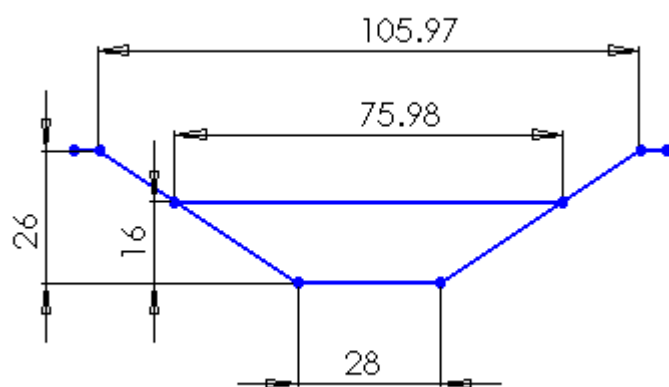


Figure 9. Secondary canal 5 (SC5) dimension in centimeter

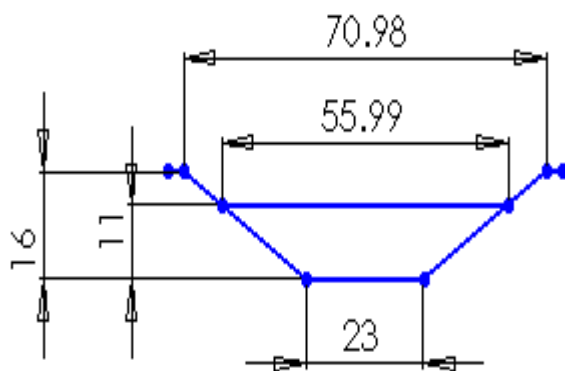


Figure 10. Tertiary canal (TC) dimension in centimeter

4.6.4.4 Division box

The discharge inlet to two way division box from secondary canal 1 (SC1) is $0.146 \text{ m}^3/\text{s}$ was divided into three.

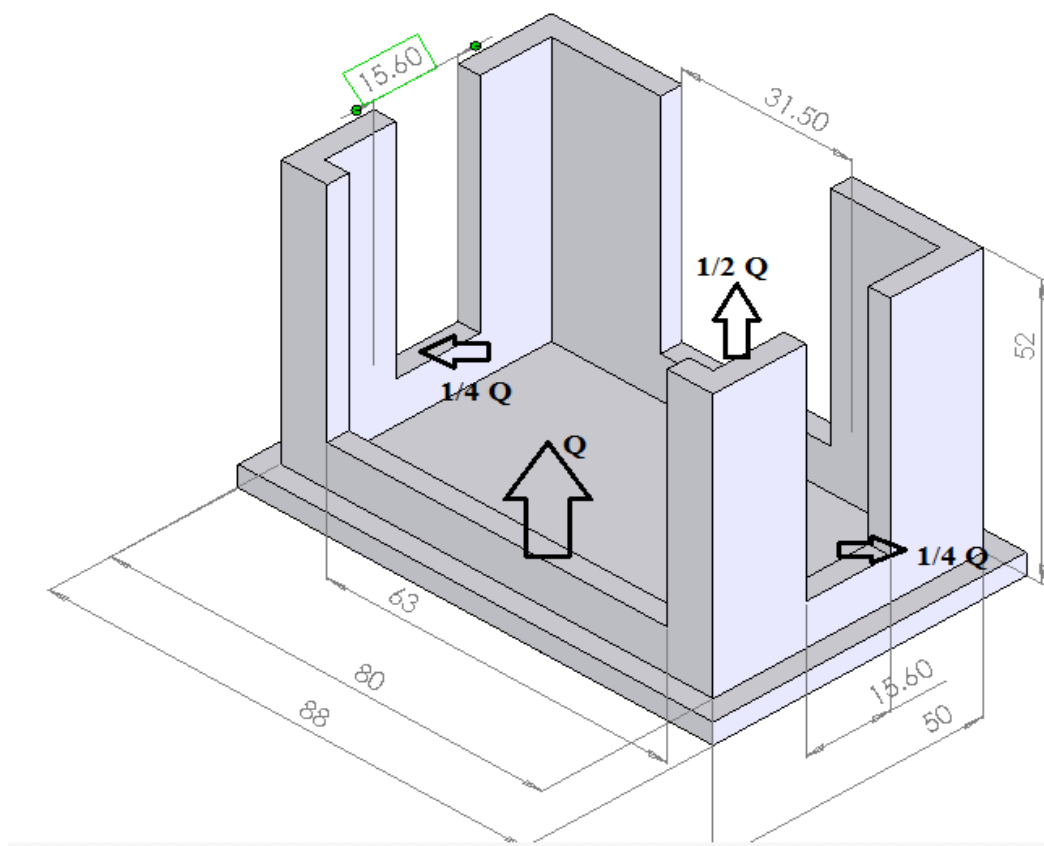


Figure 11. Three way division box 1

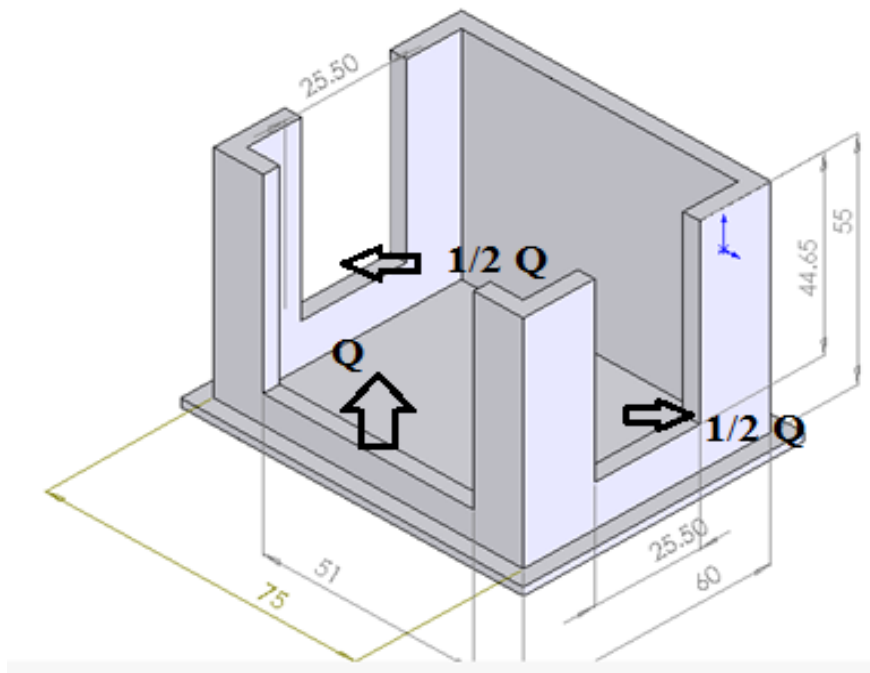


Figure 12. Two way division box 2

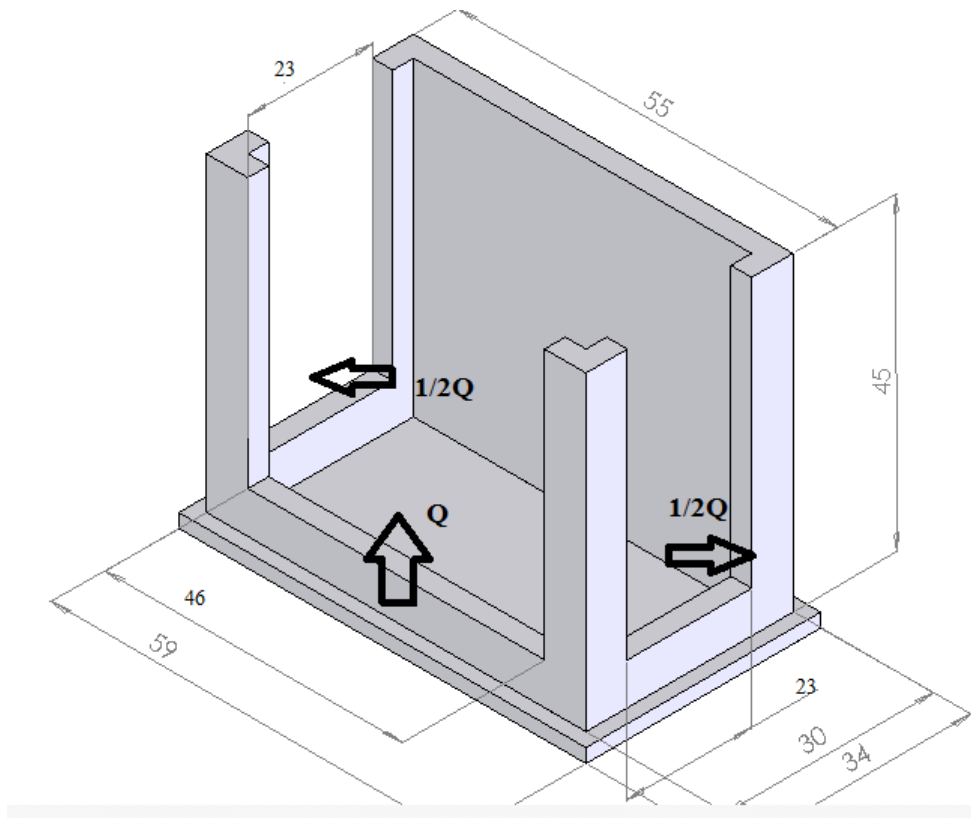


Figure 13. Two way division box 3

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

Irrigation is highly expected to play a major role in the realization of Ethiopian food security and poverty alleviation strategy. From this important viewpoint irrigation projects are widely studied, planned and implemented throughout the country. However, little or no attention is given to the monitoring and evaluation of the performance of already established irrigation schemes.

Performance evaluation for any irrigation system is essential to assess how far the goals and objectives set forth at the time of project formulation of the system have been achieved. This is a useful tool to provide necessary feedback for improving the systems management by initiating remedial measures.

This study was done on Mada Batu small scale irrigation scheme to characterize and evaluate the performance of scheme using performance indices (E_c , E_a , E_o , E_s and DU).

For this primary and secondary data collection methods were used. Primary data collection like physico-chemical properties of soil (soil texture, water holding capacity (FC and PWP), bulk density, OM, pH, electrical conductivity, soil moisture content before and after irrigation and soil infiltration rate), reservoir capacity, characterization of irrigation scheme and discharge measurement at head works (off take to main canal), upper, middle, lower in the main canals and at field inlets of selected fields of the three study area. The secondary data collected were meteorological data from National Metrological Agency and the history of the irrigation scheme from West Arsi Zone and Gedeb Asasa district Offices of Irrigation development Authority.

The characterization of the scheme was also done by field observation and measurements. Reservoir characterization was described in terms of capacity and dimensions, and main and secondary canal were described in terms of their discharge, canal dimensions, and functionality of the elements. Finally after collecting product, water productivity was calculated, comparative were examined within the scheme by irrigation efficiencies and

water productivity. The crop and irrigation water requirement of the crops were also calculated using the CROPWAT 8 software.

Currently measured capacity of reservoir has 2604 m³ live storage and 564.3 m³ dead storage. Total reservoir storage is 3168.3 m³. The main canal is the trapezoidal shape of canal that some parts are lined and others are unlined. It has different dimensions at different place but the average with 161, 59, 38.2 cm at the top, bottom and depth respectively. This is due to poor maintenance of the canal. The maximum discharge capacity of the main canal when gate was full opened at off take, upper, middle and lower stream were 70, 62, 41, 33 l/sec respectively. Most of the secondary canal was not functioning due to some part of canal like water closing gate and division box were damaged. Due to non functionality of secondary canal, the farmer used to divert water to its own way from division box reached their farm.

For three farmers' fields evaluation the average conveyance efficiency was 88.6%, 58.6% and 47.1% and water loss at the interval of 400 m, 800 m and 1200 m from off take canal were 7.98 l/s, 28.98 l/s and 37.03 l/s were determined at upper, middle and lower stream respectively. This shows that at interval of 400 m 7.98 l/s, 21 l/s and 8.05 l/s water loss from upper, middle and lower streams respectively.

Application efficiency (E_a), runoff ratio (ROR), deep percolation fraction (DPF), water storage efficiency (E_s), overall efficiency (E_o) and distribution uniformity (DU) were determined and their average values of scheme were found to be 64.54%, 12.10%, 23.29%, 82.47%, 41.47%, and 93.10% respectively. Water productivities (in terms of water use efficiency) had an increasing trend from upper stream to downstream fields and the values were of 0.74 kg/m³ for the upper and middle and 1.61 kg/m³ for lower irrigation scheme, whereas the productivity (in terms of irrigation water use efficiency) had values of 1.34 kg/m³ for the upper and middle and 3.68 kg/m³ for lower irrigation scheme.

5.2 Conclusion

The conveyance water loss of main canal at the middle stream is high than the two stream due to same trees root cracks canal bed resulting seepage loss. Due to this surge flowing of water from the main canals affecting some farmer's farm by water logging.

The result of the study also showed that the irrigation water applied to the farmer's fields was higher at upper stream scheme than the required depth to be applied per irrigation event. Even though water was not a free resource, farmers were applying excess amount of water to their fields without considering the crop water requirements of the crop. But the lower side of the study area farm was stopped to irrigate due to water not reached there.

The main problem of study area was the command area irrigated and water supply was not related. From the secondary data information the scheme was design for 200 ha of land. The gross irrigation requirement of currently irrigating command area (330 ha) was $(524 - 74.9 = 449.1 \text{ l/s})$. But the current main canal water supply measured was 70 l/s.

5.3 Recommendations

It intensively recommended for district irrigation development authority to solve the conflict between the farmer by making this research as base line (reference) further studies should be carried out to determine water supply to command area, to measure continues water flow (spring water flow from reservoir) and detail land survey for detail scheme design.

Until the solution will come (redesign implemented) the district expert give training for farmers on water use and fix the schedule depending on crop water requirement. The canal maintenance and the reservoir .cleaning were to be given the main alarm to increase the discharge and decrease the loss.

6. REFERENCES

- Abrenethy L. 1989. Performance Criteria for Irrigation Systems. Conference on Irrigation Theory and Practice, Southampton, UK.
- Adriana Marica. Short description of the CROPWAT Model. <http://agromet-cost.bo.ibimet.cnr.it/fileadmin/cost718/repository/cropwat.pdf>. Access date June 8, 2015.
- Alberf W. Marsh. Determination of Soil Moisture Levels. Cooperative Extension Service, University of California. http://www.irrec.ifas.ufl.edu/flcitrus/pdfs/short_course_and_workshop/second_international_citrus/Marsh. Accessed date June 7, 2015.
- Asawa G.L. 2008. Irrigation and Water Resources Engineering. New Delhi – 110002.
- CSA (Central Statics Authority). 2005. Agricultural sampling survey 2206/7. Report on area and production of the crop. Addis Ababa, Ethiopia.
- Chandrasekaran, B., Annadurai K. and Somasundaram, E. 2010. A Text Book of Agronomy. Daryaganj, New Delhi – 110002.
- Clemmens, A.J. and Molden, D.J. 2007. Water uses and productivity of irrigation system. Irrigation systems. 25, 247-261.
- Connellan, G. 2002. Efficient Irrigation: A Reference Manual for Turf and Landscape as Part of an Irrigation Best Management Training.
- Daniel Tedla 2007. Evaluation of Bullinegero Small-Scale Irrigation System, Benishangul-Gumuz Regional State. M. Sc Thesis. Haramaya University, Ethiopia.
- Depeweg H. and Mendez N.V. 2006. A New Approach of Sediment Transport in the Design and Operation of Irrigation Canals (Unesco-Ihe Lecture Note Series).
- FAO (Food and Agriculture Organization). 1986. Irrigation Water Management: Irrigation Water Needs. Training manual No. 3. Rome, Italy.
- FAO (Food and Agriculture Organization). 1989. Guidelines for Designing and Evaluating Surface Irrigation Systems. Irrigation and drainage paper No. 45. Rome, Italy.
- FAO (Food and Agriculture Organization). 1990. Irrigation Water Management: - Irrigation Methods. Training Manual No.5. Rome Italy.
- FAO (Food and Agriculture Organization). 1992. Scheme Irrigation Water Needs and Supply Irrigation Water Management: Training Manual No. 6. FAO, Rome.
- FAO (Food and Agriculture Organization). 1993. Canals: Irrigation Water Management Training Manual No. 7. FAO, Rome.

- FAO (Food and agricultural Organization). 1995. Irrigation in Africa in Figures: Water Reports. No. 7. FAO, Rome.
- FAO (Food and agricultural Organization). 1996. World Food Summit, 13 to 17 November 1996. FAO. Rome.
- FAO (Food and Agriculture Organization). 1997. Irrigation Potential In Africa: A Basin Approach: Land and Water Bulletin 4. Rome, Italy.
- FAO (Food and Agriculture Organization). 1997. Small-Scale Irrigation for Arid and zone. Principle and Options. FAO, Rome.
- FAO. (Food and agricultural Organization). 1998. Crop Evapotranspiration: Guidelines for Computing Crop Requirements. Irrigation and Drainage paper No. 56, FAO, Rome.
- FAO (Food and agricultural Organization). 2001. Smallholder Irrigation Technology: Prospects for Sub-Saharan Africa. International Programme for Technology and Research in Irrigation and Drainage, Knowledge Synthesis Report No.3. Rome.
- FAO (Food and Agriculture Organization). 2002. Crop Water Requirements and Irrigation Scheduling. Irrigation Manual Module 4. FAO, Harare.
- FAO (Food and Agriculture Organization). 2002. Surface Irrigation Systems Planning, Design, Operation and Maintenance: - Irrigation Manual Module 7. FAO, Harare.
- FAO (Food and Agriculture Organization). 2005. Regional Conference on Food Safety for Africa.
- FAO (Food and Agriculture Organization). 2015. Evaporation from artificial lakes and reservoirs.
- Gorantiwar, S.D. and Smout, I.K. 2005. Performance assessment of irrigation water management of heterogeneous irrigation schemes: A framework for evaluation Irrigation and Drainage Systems, 19(1), pp 1-36.
- GTP (Growth and Transformation Plan). 2010. Ethiopia's Growth and Transformation Plan (GTP). Framework for the five-year period (2010/11-2014/15)
- Israelsen, O.W. and Hansen, V.E. 1962. Flow of water into and through soils. Irrigation principles and practices. 3rd Edition, John Wiley and Sons, Inc., New York.
- Irmak, S., Odhiambo, O.L., Kranz, L.W. and Eisenhauer, E.D. 2011. Irrigation Efficiency and Uniformity, and Crop Water Use Efficiency. Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln.
- IWMI (International Water Management Institute). 2010. Irrigation potential in Ethiopia:-Constraints and opportunities for enhancing the system
- James, L.G. 1988. Principles of Farm Irrigation Design. John Wiley and Sons, Inc. New York.

- Jurriens, M., Zerihun D., Boonstra J. and Feyen J. 2001. SURDEV: Surface Irrigation Software. Design, Operation, and Evaluation of Basin, Border, and Furrow Irrigation. International Institute for Land Reclamation and Improvement (ILRI) Publication 59. Netherlands, Wageningen.
- Lesley, W. 2002. Irrigation Efficiency. Irrigation Efficiency Enhancement Report No 4452/16a
- Kedir, Y. 1988. Parshall Flume model.pdf.
- Machibya, M., Makarius, M. and Bruce, L. 2004. Draft irrigation efficiency and productivity manual - Tools for irrigation professionals and practitioners, 54.
- Majumdar D.K. 2002. Irrigation Water Management. Principle and Practice
- MCE (Metaferia Consulting Engineers). 2004. Assessment of experiences and opportunities on medium and large-scale irrigation in Ethiopia.
- Merriam, J.L., Shearer, M. N. and Burt, C. M. 1983. Evaluating Irrigation Systems and Practices. In: Design and Operation of Farm Irrigation Systems. An ASAE Monograph No. 3, American Society of Agricultural Engineers Publisher, USA. pp 721-760.
- Michael, A. M., 1997. Irrigation Theory and Practice. Evaluating Land for Irrigation Commands. Reprinted Edition, Vikas Publishing House Pvt Ltd, New Delhi, India.
- Michael, A.M. 2008. Irrigation Theory and Practice 2nd edition. Indian agricultural research institute, New Delhi. `
- Michael P. M. and John W. J. 1991. Calculating Area and Volume of Ponds and Tanks. SRAC. No. 89-38500-4516, USDA.
- Mishra, R. D. and Ahmed, M. 1990. Manual on Irrigation Agronomy. New Delhi.
- Mekonnen Ayana and Seleshi Bekele Awulachew. 2007. Comparison of irrigation performance based on management and cropping types. International Water management Institute for Nile Basin and East Africa, Arba Minch University, Arbaminch, Ethiopia.
- MoWR (Ministry of Water Resources). 1998. Abbay River Basin Integrated Development Mater Plan Project: Phase 2, vol. VI, Water Resources Development, part 2, Large Irrigation and Hydropower Dams. Report, Addis Ababa, Ethiopia. pp. 22-24.
- MoWR (Ministry of Water Resources). 2002. Water Sector Development Programme 2002-2016, Volume II: Main Report. Ministry of Water Resources, Federal Democratic Republic of Ethiopia, Addis Ababa.
- Mushtaq, A.K., Khalid, M. and Gaylord, V.S. 1997. Current Meter Discharge Measurements from Steady and Unsteady flow Condition in Irrigation Channels. Report No.T-7,Pakistan national program.

- NRCS (Natural Resources Conservation Service) 2011. Irrigation Reservoir in Conservation Practice Standard.
www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/16/nrcs143_026680.pdf.
 Accessed date November 2016.
- NRMD (Natural Resources Management Directorate). 2011. The Federal Democratic Republic of Ethiopia Ministry of Agriculture Natural Resource Sector Small-Scale Irrigation Capacity Building Strategy for Ethiopia.
- Rani,R.Y., Venkateswarao, B. and Sreekanth, S. 2011. Modernization of an Existing Irrigation Project by Performance Evaluation Using Performance Indicators. *International eJournal of Mathematics and Engineering* 141: 1273–92.
- Robel Lambiso. 2005. Assessment of Design Practices and Performance of Small Scale Irrigation Structures in South Region. M.Sc. Thesis. Arba Minch University, Ethiopia
- Sahlemedhin Sertsu and Taye Bekele. 2000. Procedure for Soil and Plant Analysis. National Soil Research Centre, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia.
- Seleshi Bekele Awulachew, D.J. Merrey, A.B. Kamara, B. Van Koppen, F. Penning de Vries and E. Boelee. 2005. Experiences and Opportunities for Promoting Small-Scale/Micro Irrigation and Rainwater Harvesting for Food Security in Ethiopia. IWMI Working Paper 98. Colombo, Sri Lanka.
- Seleshi Bekele, Aster Denekew, Makonnen Loulseged, Loiskandl, W., Mekonnen Ayana, and Tena Alamirew. 2007. Water Resources and Irrigation Development in Ethiopia. Working Paper 123. Colombo, Sri Lanka.
- Sener, M., Yiksel, A.N. and Konukcu, F. 2007. Evaluation of Hayrabolu Irrigation Scheme in Turkey Using Comparative Performance Indicators. *Journal of Tekirdag Agricultural Faculty* 4(1):43–5.
- Shibru Wakuma.2007. Performance Evaluation of Ful-Tino Smallholder Irrigation Scheme in Oromia, Ethiopia. M. Sc Thesis. Haramaya University, Ethiopia.
- Stanley, W.C. and Yerima, B. 1992. Improvement of soil services for agricultural development: guidelines for soil sampling and fertility evaluation. Ministry of Natural Resources Development and Environmental Protection, Addis Ababa, Ethiopia.
- Tanner, C.B. and Sinclair, T.R. 1983. Efficient water use in crop production: research.
- Terry, A. and Howell. 2002. Central Plains Irrigation Short course and Exposition Proceedings.
- Walker,W.R. and Skorerboe, G.V. 1987. Surface Irrigation: Theory and Practice. Prentice Hall, Englewood Cliffs, New Jersey.

World Bank, 2005. World Bank Development Indicator (WDI).World Bank, Washington DC.

Zelege Agide Dejen. 2015. Hydraulic and Operational Performance of Irrigation Schemes in View of Water Saving and Sustainability. Sugar Estates and Community Managed Schemes in Ethiopia.

Zerihun Bekele and Ketema Tilahun. 2006. On-Farm Performance Evaluation of Improved Traditional Small-Scale Irrigation Practices : A Case Study from Dire Dawa Area, Ethiopia. 83–98.

7. APPENDICES

Appendix Table 1. Sample data of average infiltration rate of the three site test plot

Elapsed time, min	2	4	6	8	10	15	20	25	30	40	50	60	75	95	115
Accumulated infiltration, mm	6	11	15	18	20	25	29	32	34	38	41	43	46	46	50
Infiltration rate, mm/hr	181.8	151.5	121.2	90.9	60.6	60.2	48.2	36.1	24.1	24	18	12	12	12	12

Appendix Table 2. Segment and total discharge of the main canal at Off take (diverging head)

Canal location	Distance (m)	AV. Velocity at 0.6 water depth (m/s)	Water depth (m)	Mean velocity (m/s)	Width (m)	Mean water depth (m)	Segment discharge (m ³ /s)
Off take (diverging head)	0.00	0.00	0.00				
	0.10	0.278	0.29	0.139	0.10	0.145	0.002
	0.155	0.29	0.34				
	0.21	0.30	0.35	0.295	0.055	0.345	0.006
	0.265	0.33	0.39				
	0.32	0.358	0.39	0.344	0.055	0.39	0.007
	0.375	0.36	0.39				
	0.43	0.37	0.4	0.365	0.055	0.395	0.008
	0.485	0.39	0.4				
	0.54	0.398	0.38	0.394	0.055	0.39	0.008
	0.595	0.41	0.39				
	0.65	0.44	0.45	0.425	0.055	0.42	0.010
	0.705	0.39	0.44				
	0.76	0.368	0.44	0.379	0.055	0.44	0.009
	0.815	0.35	0.36				
	0.87	0.30	0.42	0.325	0.055	0.39	0.007
	0.925	0.29	0.36				
	0.98	0.28	0.35	0.285	0.055	0.355	0.006
	1.035	0.289	0.34				
	1.09	0.265	0.30	0.277	0.055	0.32	0.005
	1.19	0.00	0.00	0.133	0.10	0.15	0.002

Total discharge (m³/s)	0.070
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Appendix Table 3. Segment and total discharge of the main canal at upper stream

Canal location	Distance (m)	Average Velocity at 0.6 water depth (m/s)	Depth (m)	Mean velocity (m/s)	Width (m)	Mean depth (m)	Segment discharge (m ³ /s)
Upper stream of main canal	0	0	0				
	0.08	0.24	0.36	0.12	0.08	0.18	0.002
	0.135	0.24	0.32				
	0.19	0.25	0.36	0.245	0.055	0.34	0.005
	0.245	0.32	0.4				
	0.30	0.30	0.39	0.31	0.055	0.395	0.007
	0.355	0.30	0.39				
	0.41	0.35	0.4	0.325	0.055	0.395	0.007
	0.465	0.36	0.38				
	0.52	0.35	0.35	0.355	0.055	0.365	0.007
	0.575	0.33	0.44				
	0.63	0.34	0.45	0.335	0.055	0.445	0.008
	0.685	0.30	0.44				
	0.74	0.30	0.44	0.30	0.055	0.44	0.007
	0.795	0.29	0.39				
	0.85	0.28	0.38	0.286	0.055	0.385	0.006
	0.905	0.28	0.45				
	0.96	0.272	0.4	0.276	0.055	0.425	0.006
	1.015	0.267	0.35				
	1.07	0.24	0.32	0.254	0.055	0.335	0.005
	1.15	0	0	0.12	0.08	0.16	0.002
Total discharge (m³/s)							0.062

Appendix Table 4. Segment and total discharge of the main canal at middle stream

Canal location	Distance (m)	Average Velocity at 0.6 water depth (m/s)	Depth (m)	Mean velocity (m/s)	Width (m)	Mean depth (m)	Segment discharge (m ³ /s)
Middle stream of scheme	0.00	0.00	0.00				
	0.095	0.245	0.33	0.123	0.095	0.165	0.002
	0.13	0.26	0.34				
	0.165	0.259	0.34	0.26	0.035	0.34	0.003
	0.20	0.27	0.36				
	0.235	0.298	0.36	0.284	0.035	0.36	0.004
	0.27	0.33	0.35				
	0.305	0.34	0.36	0.335	0.035	0.355	0.004
	0.34	0.331	0.35				
	0.375	0.33	0.34	0.331	0.035	0.345	0.004
	0.41	0.37	0.36				
	0.445	0.37	0.36	0.37	0.035	0.36	0.005
	0.48	0.36	0.36				

0.515	0.36	0.36	0.36	0.035	0.36	0.005
0.55	0.37	0.36				
0.585	0.36	0.36	0.365	0.035	0.36	0.005
0.62	0.31	0.36				
0.655	0.29	0.35	0.3	0.035	0.355	0.004
0.69	0.27	0.34				
0.725	0.25	0.3	0.26	0.035	0.32	0.003
0.82	0.00	0.00	0.125	0.095	0.15	0.002
Total discharge (m³/s)						0.041

Appendix Table 5. Segment and total discharge of the main canal at lower side

Canal location	Distance (m)	A v r a g e Velocity at 0.6 water depth (m/s)	Depth (m)	M e a n velocity (m/s)	Width (m)	Mean depth (m)	Segment discharge (m ³ /s)
L o w e r stream of scheme	0.00	0.00	0.00				
	0.10	0.23	0.19	0.115	0.1	0.095	0.001
	0.15	0.26	0.20				
	0.20	0.27	0.21	0.265	0.05	0.205	0.003
	0.25	0.27	0.23				
	0.3	0.298	0.24	0.284	0.05	0.235	0.003
	0.35	0.33	0.25				
	0.40	0.32	0.25	0.325	0.05	0.25	0.004
	0.45	0.332	0.25				
	0.50	0.33	0.26	0.331	0.05	0.255	0.004
	0.55	0.31	0.26				
	0.60	0.33	0.24	0.32	0.05	0.25	0.004
	0.65	0.31	0.25				
	0.70	0.32	0.26	0.315	0.05	0.255	0.004
	0.75	0.28	0.26				
	0.80	0.26	0.26	0.27	0.05	0.26	0.004
	0.85	0.27	0.23				
	0.90	0.23	0.21	0.25	0.05	0.22	0.003
	0.95	0.22	0.21				
	1.00	0.22	0.19	0.22	0.05	0.20	0.002
	1.10	0.00	0.00	0.11	0.10	0.095	0.001
Total discharge (m ³ /s)							0.033

Appendix Table 6. Average of soil moisture in percentage (%) of weight and volume base

Location	Stage	Irrigation period	Soil moisture					
			Surface (0-30 cm)			Sub-surface (30-60 cm)		
			Density (gm/cm ³)	w/w %	v/v %	Density (gm/cm ³)	w/w %	v/v %
Upper	Initial	AI	1.46	18.36	26.80	1.42	21.20	30.10
		BI	1.46	12.81	18.70	1.42	14.30	20.30
		Def.		5.55	8.10		6.90	9.80
	Dev.	AI	1.46	19.52	28.50	1.42	21.06	29.90
		BI	1.46	13.15	19.20	1.42	14.23	20.20
		Def.		6.37	9.30		6.83	9.70
	Mid	AI	1.46	19.11	27.90	1.42	21.83	31.00
		BI	1.46	12.74	18.60	1.42	14.86	21.10
		Def.		6.37	9.30		6.97	9.90
	Late	AI	1.46	19.16	27.98	1.42	21.13	30.00
		BI	1.46	12.47	18.20	1.42	15.21	21.60
		Def.		6.70	9.78		5.92	8.40
Middle	Initial	AI	1.45	18.48	26.80	1.44	19.10	27.50
		BI	1.45	12.41	18.00	1.44	12.78	18.40
		Def.		6.07	8.80		6.32	9.10
	Dev.	AI	1.45	18.83	27.30	1.44	18.68	26.90
		BI	1.45	13.66	19.80	1.44	12.64	18.20
		Def.		5.17	7.50		6.04	8.70
	Mid.	AI	1.45	20.00	29.00	1.44	19.51	28.10
		BI	1.45	13.24	19.20	1.44	13.54	19.50
		Def.		6.76	9.80		5.97	8.60
	Late	AI	1.45	18.55	26.90	1.44	19.44	28.00
		BI	1.45	12.00	17.40	1.44	13.06	18.80
		Def.		6.55	9.50		6.39	9.20
Lower	Initial	AI	1.47	17.21	25.30	1.45	19.17	27.80
		BI	1.47	11.16	16.40	1.45	13.10	19.00
		Def.		6.05	8.90		6.07	8.80
	Dev.	AI	1.47	17.01	25.00	1.45	18.48	26.80
		BI	1.47	11.70	17.20	1.45	13.17	19.10
		Def.		5.31	7.80		5.31	7.70
	Mid	AI	1.47	16.94	24.90	1.45	18.83	27.30
		BI	1.47	10.54	15.50	1.45	13.03	18.90
		Def.		6.39	9.40		5.79	8.40
	Late	AI	1.47	17.28	25.40	1.45	17.84	25.87
		BI	1.47	10.95	16.10	1.45	12.86	18.65
		Def.		6.33	9.30		4.98	7.22

AI=after irrigation BF=before irrigation, Def. =different between AI and BI

Appendix Table 7. Irrigation schedule of farmers and Purshall Flume water measurement at three location of irrigation scheme

[illegible]

Appendix Table 8. Reference Evapotranspiration (ET_o) of Gedab Asasa from nearest station

Country: - Ethiopia

Station: - Asasa

Altitude: - 2245

Longitude:-5.91

Longitude: - 38.24

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sunshine hours	Radiation MJ/m ² /day	ET _o mm/day
January	10.4	25.4	55	181	8.6	20.9	4.17
February	11	25.9	50	173	8.6	22	4.51
March	12.7	27.3	51	164	8.2	22.1	4.72
April	13.7	27.1	60	156	7.4	20.8	4.41
May	13.6	27.1	61	164	7.5	20.3	4.33
June	13.1	25.7	65	173	7.4	19.6	4.07
July	12.8	23.4	72	181	5.1	16.4	3.38
August	12.9	23.6	76	147	5.6	17.7	3.42
September	12.2	24	72	112	6.2	18.9	3.6
October	11.7	25	66	173	8.5	21.9	4.2
November	10.4	24.9	61	199	9	21.6	4.19
December	9.7	24.5	57	199	9.4	21.6	4.14
Average	12	25.3	62	168	7.6	20.3	4.1

Appendix Table 9. Average of rainfall data (1991-2011) of study area from Gedab Asasa station.

Station:- Gadeb Asasa

Eff. rain method:- USDA S.C. Method

Month	Rain (mm)	Eff. Rain (mm)
January	30.7	29.2
February	31.2	29.6
March	67.3	60.1
April	153.2	115.6
May	180.2	128.2
June	81.6	70.9
July	54.9	50.1
August	70.5	62.5
September	81.4	70.8

October	164	121
November	62.5	56.3
December	18.1	17.6
Total	995.6	811.9

Appendix Table 10. Crop water requirement and irrigation water requirement of potato crop

Eto station:- Asasa

Crop:- Potato

Raion station :- Asasa

Plant date:-14/12

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	2	Init	0.5	2.07	14.5	2.5	12.8
Dec	3	Init	0.5	2.08	22.8	5.6	17.3
Jan	1	Deve	0.51	2.14	21.4	8.8	12.6
Jan	2	Deve	0.69	2.87	28.7	10.2	18.4
Jan	3	Deve	0.92	3.93	43.3	10.1	33.2
Feb	1	Mid	1.13	4.96	49.6	8.9	40.7
Feb	2	Mid	1.16	5.23	52.3	8.5	43.8
Feb	3	Mid	1.16	5.32	42.5	12.3	30.2
Mar	1	Mid	1.16	5.4	54	15.9	38.1
Mar	2	Mid	1.16	5.48	54.8	18.9	35.9
Mar	3	Late	1.12	5.16	56.7	25.4	31.3
Apr	1	Late	0.98	4.41	44.1	33.7	10.4
Apr	2	Late	0.84	3.71	37.1	40.5	0
Apr	3	Late	0.76	3.32	6.6	8.3	6.6
					528.4	209.5	331.3

Appendix Table 11. Crop water requirement and irrigation water requirement of garlic

Eto station:- Asasa

Crop:- Garlic

Raion station :- Asasa

Plant date:-14/12

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	2.00	Init	0.70	2.90	20.30	2.50	18.60
Dec	3.00	Deve	0.71	2.94	32.30	5.60	26.80
Jan	1.00	Deve	0.82	3.42	34.20	8.80	25.40
Jan	2.00	Deve	0.97	4.03	40.30	10.20	30.10
Jan	3.00	Mid	1.06	4.53	49.80	10.10	39.70
Feb	1.00	Mid	1.06	4.66	46.60	8.90	37.70
Feb	2.00	Mid	1.06	4.77	47.70	8.50	39.30
Feb	3.00	Mid	1.06	4.85	38.80	12.30	26.50
Mar	1.00	Mid	1.06	4.93	49.30	15.90	33.40
Mar	2.00	Mid	1.06	5.00	50.00	18.90	31.10
Mar	3.00	Mid	1.06	4.89	53.80	25.40	28.40
Apr	1.00	Late	1.05	4.74	47.40	33.70	13.70
Apr	2.00	Late	1.02	4.51	45.10	40.50	4.60
Apr	3.00	Late	0.99	4.36	43.60	41.30	2.30
May	1.00	Late	0.97	4.21	42.10	43.50	0.00
May	2.00	Late	0.95	4.11	8.20	9.20	8.20
					649.60	295.30	365.60

Appendix Table 12. Crop water requirement and irrigation water requirement of carrot

Eto station:- Asasa

Crop:- Carrot

Raion station :- Asasa

Plant date:-14/12

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	2.00	Init	0.70	2.90	20.30	2.50	18.60
Dec	3.00	Init	0.70	2.91	32.00	5.60	26.40
Jan	1.00	Deve	0.74	3.09	30.90	8.80	22.20
Jan	2.00	Deve	0.86	3.59	35.90	10.20	25.70
Jan	3.00	Deve	0.99	4.23	46.50	10.10	36.40
Feb	1.00	Mid	1.06	4.66	46.60	8.90	37.70
Feb	2.00	Mid	1.06	4.77	47.70	8.50	39.30
Feb	3.00	Mid	1.06	4.85	38.80	12.30	26.50
Mar	1.00	Mid	1.06	4.92	49.20	15.90	33.40
Mar	2.00	Mid	1.06	5.00	50.00	18.90	31.10
Mar	3.00	Late	1.04	4.81	52.90	25.40	27.50
Apr	1.00	Late	0.99	4.46	44.60	33.70	10.90
Apr	2.00	Late	0.95	4.21	8.40	8.10	8.40
					503.90	168.80	343.90

Appendix Table 13. Crop water requirement and irrigation water requirement of cabbage

Eto station:- Asasa

Crop:- Cabbage

Raion station :- Asasa

Plant date:-14/12

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	2	Init	0.70	2.90	20.30	2.50	18.60
Dec	3	Init	0.70	2.91	32.00	5.60	26.40
Jan	1	Init	0.70	2.91	29.10	8.80	20.40
Jan	2	Init	0.70	2.92	29.20	10.20	19.00
Jan	3	Deve	0.72	3.10	34.10	10.10	24.00
Feb	1	Deve	0.78	3.45	34.50	8.90	25.60
Feb	2	Deve	0.84	3.80	38.00	8.50	29.50
Feb	3	Deve	0.90	4.10	32.80	12.30	20.50
Mar	1	Deve	0.95	4.41	44.10	15.90	28.20
Mar	2	Deve	1.01	4.75	47.50	18.90	28.60
Mar	3	Mid	1.05	4.84	53.30	25.40	27.90
Apr	1	Mid	1.05	4.74	47.40	33.70	13.70
Apr	2	Mid	1.05	4.64	46.40	40.50	5.80
Apr	3	Mid	1.05	4.61	46.10	41.30	4.80
May	1	Mid	1.05	4.58	45.80	43.50	2.20
May	2	Late	1.03	4.44	44.40	46.00	0.00
May	3	Late	0.97	4.12	28.80	24.60	0.00
					653.70	356.70	295.10

Appendix Table 14. Irrigation schedule of potato

Date	Day	Stage	Rain mm	Ks fract.	ETa %	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
14-Dec	1	Init	0	0.67	67.00	52.00	31.70	0.00	0.00	52.80	6.11
22-Dec	9	Init	0	1.00	100.00	26.00	17.10	0.00	0.00	28.60	0.41
31-Dec	18	Init	0	1.00	100.00	26.00	17.80	0.00	0.00	29.70	0.38
12-Jan	30	Dev	0	1.00	100.00	27.00	20.50	0.00	0.00	34.10	0.33
22-Jan	40	Dev	0	1.00	100.00	31.00	25.40	0.00	0.00	42.30	0.49
30-Jan	48	Dev	0	1.00	100.00	30.00	26.10	0.00	0.00	43.60	0.63
06-Feb	55	Dev	0	1.00	100.00	32.00	29.10	0.00	0.00	48.40	0.80
12-Feb	61	Mid	0	1.00	100.00	34.00	30.30	0.00	0.00	50.50	0.97
18-Feb	67	Mid	0	1.00	100.00	30.00	27.00	0.00	0.00	45.00	0.87
25-Feb	74	Mid	0	1.00	100.00	34.00	30.40	0.00	0.00	50.60	0.84
05-Mar	82	Mid	0	1.00	100.00	32.00	29.20	0.00	0.00	48.70	0.70
11-Mar	88	Mid	0	1.00	100.00	30.00	27.10	0.00	0.00	45.10	0.87
19-Mar	96	Mid	0	1.00	100.00	31.00	28.30	0.00	0.00	47.20	0.68
01-Apr	109	End	0	1.00	100.00	40.00	36.20	0.00	0.00	60.30	0.54
22-Apr	End	End	0	1.00	100.00	20.00					

Appendix Table 15. Irrigation schedule of garlic

Date	Day	Stage	Rain	Ks	ETa	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
14-Dec	1	Init	0	0.71	71	55	25.1	0	0	41.9	4.85
19-Dec	6	Init	0	1	100	30	15.7	0	0	26.2	0.61
25-Dec	12	Init	0	1	100	31	18.2	0	0	30.4	0.59
01-Jan	19	Dev	0	1	100	34	22.3	0	0	37.1	0.61
09-Jan	27	Dev	0	1	100	31	23.2	0	0	38.6	0.56
16-Jan	34	Dev	0	1	100	31	26	0	0	43.4	0.72
24-Jan	42	Mid	0	1	100	32	28.9	0	0	48.2	0.7
01-Feb	50	Mid	0	1	100	34	31	0	0	51.7	0.75
09-Feb	58	Mid	0	1	100	31	28	0	0	46.7	0.68
16-Feb	65	Mid	0	1	100	32	28.9	0	0	48.2	0.8
22-Feb	71	Mid	0	1	100	32	28.8	0	0	48	0.93
01-Mar	78	Mid	0	1	100	30	27.4	0	0	45.6	0.75
10-Mar	87	Mid	0	1	100	34	31	0	0	51.6	0.66
20-Mar	97	Mid	0	1	100	33	30	0	0	49.9	0.58
31-Mar	108	Mid	0	1	100	32	28.8	0	0	48	0.51
12-Apr	120	End	0	1	100	31	28	0	0	46.6	0.45
12-May	End	End	0	1	100	23					

Appendix Table 16. Irrigation schedule of carrot

Date	Day	Stage	Rain mm	Ks fract.	ETa %	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
14-Dec	1	Init	0.00	0.67	67.00	53.00	39.60	0.00	0.00	66.00	7.64
21-Dec	8	Init	0.00	1.00	100.00	25.00	19.70	0.00	0.00	32.90	0.54
30-Dec	17	Init	0.00	1.00	100.00	27.00	21.90	0.00	0.00	36.50	0.47
09-Jan	27	Dev	0.00	1.00	100.00	28.00	23.10	0.00	0.00	38.50	0.45
19-Jan	37	Dev	0.00	1.00	100.00	30.00	26.20	0.00	0.00	43.60	0.51
28-Jan	46	Dev	0.00	1.00	100.00	32.00	28.10	0.00	0.00	46.90	0.60
04-Feb	53	Mid	0.00	1.00	100.00	30.00	27.10	0.00	0.00	45.20	0.75
11-Feb	60	Mid	0.00	1.00	100.00	31.00	28.10	0.00	0.00	46.80	0.77
19-Feb	68	Mid	0.00	1.00	100.00	33.00	29.40	0.00	0.00	49.10	0.71
26-Feb	75	Mid	0.00	1.00	100.00	30.00	27.20	0.00	0.00	45.40	0.75
06-Mar	83	Mid	0.00	1.00	100.00	34.00	30.80	0.00	0.00	51.40	0.74
12-Mar	89	Mid	0.00	1.00	100.00	33.00	29.70	0.00	0.00	49.50	0.95
20-Mar	97	Mid	0.00	1.00	100.00	33.00	30.00	0.00	0.00	49.90	0.72
02-Apr	110	End	0.00	1.00	100.00	41.00	37.00	0.00	0.00	61.70	0.55
12-Apr	End	End	0.00	1.00	100.00	24.00					

Appendix Table 17. Irrigation schedule of cabbage

Date	Day	Stage	Rain mm	Ks fract.	ETa %	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
14-Dec	1	Init	0.00	0.91	91.00	54.00	40.20	0.00	0.00	67.00	7.76
29-Dec	16	Init	0.00	1.00	100.00	48.00	37.40	0.00	0.00	62.30	0.48
15-Jan	33	Init	0.00	1.00	100.00	45.00	36.20	0.00	0.00	60.40	0.41
01-Feb	50	Dev	0.00	1.00	100.00	48.00	39.20	0.00	0.00	65.30	0.44
16-Feb	65	Dev	0.00	1.00	100.00	49.00	41.60	0.00	0.00	69.30	0.53
01-Mar	78	Dev	0.00	1.00	100.00	45.00	39.10	0.00	0.00	65.20	0.58
15-Mar	92	Dev	0.00	1.00	100.00	46.00	40.60	0.00	0.00	67.60	0.56
31-Mar	108	Mid	0.00	1.00	100.00	47.00	41.90	0.00	0.00	69.80	0.50
27-May	End	End	0.00	1.00	0.00	0.00					

Appendix Table 18. Scheme water supply to command for four crop patterns

[illegible]

Appendix Table 19. Discharge required and discharge calculated of Main canal

Q _{req}	d	b	k	n	s	A	P	R	R ^{2/3}	AR ^{2/3}	1/n	S ^{1/2}	Q _{cal}	d/b
0.524	0.35	0.70	1.50	0.02	0.003	0.43	1.96	0.22	0.36	0.16	45.45	0.05	0.387	0.50
0.524	0.35	0.75	1.50	0.02	0.003	0.45	2.01	0.22	0.37	0.16	45.45	0.05	0.407	0.47
0.524	0.40	0.70	1.50	0.02	0.003	0.52	2.14	0.24	0.39	0.20	45.45	0.05	0.504	0.57
0.524	0.40	0.75	1.50	0.02	0.003	0.54	2.19	0.25	0.39	0.21	45.45	0.05	0.528	0.53
0.524	0.40	0.74	1.50	0.02	0.003	0.54	2.18	0.25	0.39	0.21	45.45	0.05	0.523	0.54

d =Water depth, b=Canal width, k=Side slope, n= Manning coefficient, s= Bed slope, A= Area, P=Perimeter, R= Hydraulic radius, Q_{req}=Discharge required, Q_{cal}=Discharge required

Appendix Table 20. Discharge required and discharge calculated of secondary canal 1 (SC1)

Q _{req}	d	b	k	n	s	A	P	R	R ^{2/3}	AR ^{2/3}	1/n	S ^{1/2}	Q _{cal}	d/b
0.146	0.22	0.45	1.50	0.02	0.003	0.17	1.24	0.14	0.27	0.05	45.45	0.05	0.114	0.49
0.146	0.23	0.45	1.50	0.02	0.003	0.18	1.28	0.14	0.27	0.05	45.45	0.05	0.124	0.51
0.146	0.23	0.50	1.50	0.02	0.003	0.19	1.33	0.15	0.28	0.05	45.45	0.05	0.134	0.46
0.146	0.24	0.45	1.50	0.02	0.003	0.19	1.32	0.15	0.28	0.05	45.45	0.05	0.135	0.53
0.146	0.24	0.49	1.50	0.02	0.003	0.20	1.36	0.15	0.28	0.06	45.45	0.05	0.144	0.49
0.146	0.24	0.50	1.50	0.02	0.003	0.21	1.37	0.15	0.28	0.06	45.45	0.05	0.146	0.48

d =Water depth, b=Canal width, k=Side slope, n= Manning coefficient, s= Bed slope, A= Area, P=Perimeter, R= Hydraulic radius, Q_{req}=Discharge required, Q_{cal}=Discharge required

Appendix Table 21. Discharge required and discharge calculated of secondary canal 3 (SC3)

Q _{req}	d	b	k	n	s	A	P	R	R ^{2/3}	AR ^{2/3}	1/n	S ^{1/2}	Q _{cal}	d/b
0.073	0.17	0.35	1.50	0.02	0.003	0.10	0.96	0.11	0.22	0.02	45.45	0.05	0.058	0.49
0.073	0.17	0.40	1.50	0.02	0.003	0.11	1.01	0.11	0.23	0.03	45.45	0.05	0.064	0.43
0.073	0.18	0.35	1.50	0.02	0.003	0.11	1.00	0.11	0.23	0.03	45.45	0.05	0.064	0.51
0.073	0.18	0.40	1.50	0.02	0.003	0.12	1.05	0.11	0.24	0.03	45.45	0.05	0.071	0.45
0.073	0.19	0.36	1.50	0.02	0.003	0.12	1.05	0.12	0.24	0.03	45.45	0.05	0.073	0.53

d =Water depth, b=Canal width, k=Side slope, n= Manning coefficient, s= Bed slope, A= Area, P=Perimeter, R= Hydraulic radius, Q_{req}=Discharge required, Q_{cal}=Discharge required

Appendix Table 22. Discharge required and discharge calculated of secondary canal 4 (SC4)

Q _{req}	d	b	k	n	s	A	P	R	R ^{2/3}	AR ^{2/3}	1/n	S ^{1/2}	Q _{cal}	d/b
0.036	0.14	0.24	1.50	0.02	0.003	0.06	0.74	0.08	0.19	0.01	45.45	0.05	0.030	0.58
0.036	0.14	0.25	1.50	0.02	0.003	0.06	0.75	0.09	0.19	0.01	45.45	0.05	0.031	0.56
0.036	0.15	0.24	1.50	0.02	0.003	0.07	0.78	0.09	0.20	0.01	45.45	0.05	0.034	0.63
0.036	0.15	0.25	1.50	0.02	0.003	0.07	0.79	0.09	0.20	0.01	45.45	0.05	0.035	0.60
0.036	0.15	0.26	1.50	0.02	0.003	0.07	0.80	0.09	0.20	0.01	45.45	0.05	0.036	0.58

d =Water depth, b=Canal width, k=Side slope, n= Manning coefficient, s= Bed slope, A= Area, P=Perimeter, R= Hydraulic radius, Q_{req}=Discharge required, Q_{cal}=Discharge required

Appendix Table 23. Discharge required and discharge calculated of secondary canal 5 (SC5)

Q _{req}	d	b	k	n	s	A	P	R	R ^{2/3}	AR ^{2/3}	1/n	S ^{1/2}	Q _{cal}	d/b
0.044	0.15	0.26	1.50	0.02	0.003	0.07	0.80	0.09	0.20	0.01	45.45	0.05	0.037	0.58
0.044	0.15	0.28	1.50	0.02	0.003	0.08	0.82	0.09	0.20	0.02	45.45	0.05	0.038	0.54
0.044	0.15	0.30	1.50	0.02	0.003	0.08	0.84	0.09	0.21	0.02	45.45	0.05	0.040	0.50
0.044	0.16	0.25	1.50	0.02	0.003	0.08	0.83	0.09	0.21	0.02	45.45	0.05	0.041	0.64
0.044	0.16	0.28	1.50	0.02	0.003	0.08	0.86	0.10	0.21	0.02	45.45	0.05	0.044	0.57

d =Water depth, b=Canal width, k=Side slope, n= Manning coefficient, s= Bed slope, A= Area, P=Perimeter, R= Hydraulic radius, Q_{req}=Discharge required, Q_{cal}=Discharge required

Appendix Table 24. Discharge required and discharge calculated of tertiary canal (TC)

Q _{req}	d	b	k	n	s	A	P	R	R ^{2/3}	AR ^{2/3}	1/n	S ^{1/2}	Q _{cal}	d/b
0.018	0.10	0.20	1.50	0.02	0.003	0.04	0.56	0.06	0.16	0.01	45.45	0.05	0.014	0.50
0.018	0.10	0.23	1.50	0.02	0.003	0.04	0.59	0.06	0.16	0.01	45.45	0.05	0.015	0.43
0.018	0.11	0.23	1.50	0.02	0.003	0.04	0.63	0.07	0.17	0.01	45.45	0.05	0.018	0.48
0.018	0.11	0.24	1.50	0.02	0.003	0.04	0.64	0.07	0.17	0.01	45.45	0.05	0.019	0.46
0.018	0.11	0.25	1.50	0.02	0.003	0.05	0.65	0.07	0.17	0.01	45.45	0.05	0.019	0.44

d =Water depth, b=Canal width, k=Side slope, n= Manning coefficient, s= Bed slope, A= Area, P=Perimeter, R= Hydraulic radius, Q_{req}=Discharge required, Q_{cal}=Discharge required

Appendix Table 25. Redesigning procedure of reservoir and iteration

Gross irrigation requirement = 263.08 l/s for 24 hour

Operational scheme irrigation needs = 524 l/s for 12 hour per day

Average continues flow with canal supply = 50 l/s for 12 hour per day

Deficiency of scheme water supply per second = 524-50 l/s = 474 l/s

Daly deficiency of scheme water supply per day = 474 l/s*12 hr/day *60min/hr*60min/sec

$$= 20,476,800 \text{ l/day}$$

$$= 20,476.8 \text{ m}^3/\text{day}$$

Therefore this is the redesigned reservoir capacity

$V_{\text{req}}(\text{m}^3)$	b1(m)	b2(m)	$(b1+b2)/2(\text{m})$	d(m)	A(m)	L(m)	$V_{\text{cal}} (\text{m}^3)$
20,476.80	54	50	52	4	208	60	12,480.00
20,476.80	60	52	56	4	224	80	17,920.00
20,476.80	65	55	60	4	240	86	20,640.00
20,476.80	65	56	60.5	4	242	86	20,812.00

V_{req} and V_{cal} volume of water required calculated, b1 and b2 top and bottom width of reservoir, L= length and A=

area



Appendix Figure 1. Soil sample for bulky density and moisture determination





Appendix Figure 3. Field observation with adviser



Appendix

Figure 4. Area of scheme that not serving farmer due to absence of water in main canal



Appendix Figure 5. Reservoir storage of the scheme