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ASSESSMENT OF SMALL SCALE IRRIGATION USING COMPARATIVE PERFORMANCE INDICATORS ON TWO SELECTED SCEMES IN UPPER AWASH RIVER VALLEY

BY

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DEPARTMENT OF AGRICULTURAL ENGINEERING

SOIL AND WATER ENGINEERING PROGRAMME

(IRRIGATION ENGINEERING)

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Title of Thesis

Assessment of Small Scale Irrigation Using Comparative Performance Indicators on Some Selected Farms in Upper Awash River Valley

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ASSESSMENT OF SMALL SCALE IRRIGATION USING COMPARATIVE PERFORMANCE INDICATORS ON TWO SELECTED SCHEMES IN UPPER AWASH RIVER VALLEY

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By

YUSUF KEDIR HASSEN

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

Name	Yusuf Kedir Hassen
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This thesis is especially dedicated to my mother, Mulunesh Awol.

And to all my families for their love and care.

Biography

The author was born in 1974 in Mojo town of East Shoa administrative zone. He attended his primary education at Mojo No. 1 Elementary School and completed his secondary school at Mojo High School in 1992.

After taking the Ethiopian School Leaving Certificate Examination (ESLCE), he joined the Alemaya University of Agriculture in 1994 and graduated with B.Sc. degree in Agricultural Engineering in July 1998.

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List of Acronyms and abbreviations

AMD	Available Moisture Deficit
CSA	Central Statistics Authority
CWR	Crop Water Requirements
DA	Development Agent
DB	Bulk Density
DU	Distribution Uniformity
E_a	Application Efficiency
EARO	Ethiopian Agricultural Research Organization
EC_e	Soil Exchangeable Cation
E_r	Storage Efficiency
ET	Evapotranspiration
ET_c	Crop Evapotranspiration
ET_o	Reference Evapotranspiration
FAO	Food and Agricultural Organization
FC	Field Capacity
FSS	Financial Self Sufficiency
FMIS	Farmer Managed Irrigation System
GRI	Gross Return On Investment
ha	hectares
ICID	International Commission on Irrigation and Drainage
IDD	Irrigation Development Division
IIMI	International Irrigation Management Institution
ILRI	International Livestock Research Institute
IR	Irrigation requirements
IWMI	International Water Management Institution
IWR	Irrigation Water Requirements
MoA	Ministry of Agriculture
M.s.l.	mean sea level
MWR	Ministry of Water Resource

NGO	Non Governmental Organization
PA	Peasant Associations
PC	Producers Cooperatives
PNW	Present Net Worth
PWP	Permanent Wilting Point
RAM	Readily Available Moisture
RH	Relative humidity
RIS	Relative Irrigation Supply
RPIP	Research Program on Irrigation Performance
RWS	Relative Water Supply
SCS	Soil Conservation Service
SSI	Small-Scale Irrigation
TAW	Total Available Moisture
USDA	United State Development Agency
WDC	Water Delivery Capacity
WUA	Water Users Associations

ASSESSMENT OF SMALL SCALE IRRIGATION USING COMPARATIVE PERFORMANCE INDICATORS ON Two SELECTED SCHEMES IN UPPER AWASH RIVER VALLEY

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ABSTRACT

This study attempted to introduce the concept of comparative performance indicators with some process indicators such as application, storage and distribution efficiencies as a tool to evaluate the performance of two small-scale irrigation schemes selected in the Upper Awash Valley. The irrigation schemes were Batu Degaga with 60 ha of irrigable land and Doni with 122 ha of irrigable area. The criteria for selection were their proximity to Melkassa Research Center, availability of secondary data and organizational set up.

Collecting primary and secondary data of each irrigation schemes has been carried out by the study. Primary data collection included canal water flow measurement at Doni diversion, pump discharge of Batu Degaga, moisture contents determination of the soils, measurement of depth of water applied to the fields using three inches parshal flumes.

The secondary data collection has been carried out in collaboration with organizations and government officials, and included total yields, farm gate prices of irrigated crops, area irrigated per crop per season or per year, crop types, incomes generated by the irrigation associations and cropping pattern.

The comparative indicators rely on the availability of secondary data. Even though getting complete data, required to calculate all the external indicators (the nine indicators) for each small-scale irrigation project, is difficult the two-irrigation projects were compared using minimum sets of comparative indicators.

In order to evaluate the irrigation water use efficiency of farmers at field level three farmers were selected from each irrigation projects in relation to their location (from the head, middle and tail end water users). The parameters used to compare the efficiencies at field level were application, storage and distribution efficiencies.

From the analyses of the comparative performance indicators, the result of the ratios of RWS and RIS were 2.32 and 2.57 for Batu Degaga while 2.24 and 2.76 for Doni irrigation

projects, respectively. The values of WDC and GRI were in the order of 0.77 and 13.60% for Batu Degaga, the corresponding values for Doni were 1.83 and 27.55%.

This indicated that irrigation water is not a constraint and higher amount of water was diverted (generous supply of water) at Doni than Batu Degaga. And at Doni there was also high rate of return on investment than Batu Degaga.

Outputs per cropped area of the two projects were more or less equal (5,027.25 for Batu Degaga and 5,018.90 for Doni) but the value of the output per command area of Doni (7,590.00) was greater than the value of Batu Degaga (6,625.83). The output per unit irrigation supply for Batu Degaga was 1.14 while Doni was 0.67. Output per water consumed varied from 2.45 to 1.14 birr per m^3 *for Batu Degaga and Doni, respectively.*

The FSS of the Batu Degaga was in the ranges of 50.96% to 217.83% and FSS for Doni ranges from 85.25% to 970.49%.

Regarding the output per area, Doni was better than Batu Degaga, but for the output per water supply the inverse was true that is, Batu Degaga was better than Doni. Since the intention of the analysis was to investigate how the performances of the irrigation projects were consistent, Doni irrigation has been performing better than Batu.

The application efficiencies of the selected farmer's field from the two irrigation projects varied from 31.46% to 64.29% and storage efficiencies were in the order of 80.41% to 104.70%. Distribution efficiency of the entire selected field was 100%.

The three selected irrigated fields at Batu Degaga could be considered as 'in the order of similar condition' for their irrigation water management efficiencies. But at Doni, the three plots for irrigation water, Field II was more efficient than Field I. Field III was the least efficient.

1 INTRODUCTION

1.1 Statements of the problem

The outlook for the food security of many developing nations is a cause for serious concern. The problem of food security is exacerbated by the rapid growth of population and hence of the demand for food. In fact, the prices of foodstuffs in the world market have recently begun to rise. Beyond that looms the specter of a fundamental change in climate that may increase the severity and variability of weather and thus disrupt established systems of production. Such a change could require expensive investments in modifying existing systems and establishing new ones (FAO, 1997).

Clearly, irrigation can and should play an important role in raising and stabilizing food production, especially in the less-developed parts of Africa-south of the Sahara.

Although the Ethiopian renewable surface and groundwater amounts to 123 and 2.6 billion cubic meters per annum, respectively, its distribution in terms of area and season does not give adequate opportunity for sustainable growth to the economy. The intensity of recurrent droughts affects the livelihoods of the agricultural communities and the whole economy. Even in a year of good rain, the occurrence of floods affects the livelihoods of riparian residents with little capacity to neither protect from the seasonal flood nor mitigate the impact (McCornick et al, 2003). Further more according to McCornick et al

(2003), the total irrigated area in Ethiopian river basins amounts to 161,790 ha, which is only 4.4%.

As part of the development community's fascination with the field of appropriate technologies, a range of technologies, techniques and practices have been developed over the years on behalf of smallholders. However, many, if not most, technologies have not been successful in their performance, application, dissemination or adoption. Development agencies have tried to encourage farmers to adopt bush pumps, rope-and-washer pumps, rower pumps, treadle pumps, pitcher pot systems, drag-hose sprinklers, hydraulic ram pumps, micro-irrigation systems, windmills, water harvesting techniques and a host of other technologies with mixed success. While it may be that some of the technologies simply did not perform up to the expectations, there is a natural tendency to over-emphasize the technology itself rather than pay attention to the process by which it is identified, modified, and disseminated. All too frequently, the end customer - the farmer - has been left out of the process altogether (Jorma, 1999).

State run farms, which include large-scale irrigation systems, were reiterated as major components of efforts to develop the country's agricultural sector, notably in the Awash Valley. However, productivity of these tops–down managed systems over the decades has been disappointing—the farms have been beset by a number of environmental, technical and socio-economic constraints. The large scale systems in the Awash basin and elsewhere suffer from water management practices that have resulted in rising ground water tables and secondary soil salinization where large tracts of land have gone out of production (EARO, 2002). Besides management problems of large-scale irrigations, most existing modern irrigation devices do not fit the plots of smallholders, and are far too expensive (in terms of capital or running costs) to be affordable. One key, then, to increasing the agricultural productivity of small farmers is access to affordable and efficient irrigation technologies.

Irrigation in the Awash basin is river-fed and poor management of irrigation systems are compounded by competition for water access by crop, livestock, small holders and large commercial farm enterprises, like sugar factories. Small-scale irrigation, defined as less than 200 ha, in the peasant sector has a relatively longer history in certain parts of Ethiopia. Unlike the large-scale irrigation in the basin, however, it has been given little attention on the development, operation (management) and improvement of the sector EARO (2002). While no reliable data on the area of small-scale irrigation are available, estimates in the Awash Basin indicate a total irrigated area of about 20,000 ha (most of which are in the uplands) and it can be expanded to 35,000 ha (Halcrow, 1989). More recently small-scale irrigation developments have been gradually expanding through the initiative of NGOs, farmer cooperatives, private investors and individual farmers. According to McCornick et al (2003), the figure for the potential area of traditional irrigation in the country as a whole reaches around 352 thousand while only 65 thousand hectare is under irrigation.

The availability of irrigation water management information on a detailed scale like farmer fields or for entire river basins is not common. Data to quantify performance indicators are rarely collected (Bastiaanssen and Bos, 1999). To make a performance-oriented approach effective, it is necessary to retrofit new techniques and approaches to existing management practices.

One particularly pressing resource management challenge to Ethiopia is to improve the performance of small-scale irrigation systems. These systems will play an important role in providing food for the country's growing population. At the same time, they have the potential to waste, even degrade, vital soil and water resources. In recognition to both the promise and hazards associated with irrigation, evaluating irrigation performance has now become of a paramount importance.

In addition to using process indicators (like irrigation water use efficiencies), the International Water Management Institute (IWMI) suggests using a minimum set of comparative indicators to assess hydrological, agronomic, economic, financial, and environmental performances of irrigation systems. The aim of applying comparative indicators is to evaluate outputs and impacts of irrigation management practices, interventions across different systems and system levels, as well as to compare various irrigation seasons and technologies with one another. And also, these indicators are small, not data-intensive and are cost-effective (Kloezen and Garces-Restrepo, 1998).

Besides the poor performance of the irrigations in the country as stated earlier, evaluation of small-scale irrigation systems is not common; this is particularly true in using the *comparative performance indicators.* Hence, this study attempts to introduce the concept of comparative performance indicators (with some process indicators) as a tool to evaluate the performance of small-scale irrigations endeavors in the Upper Awash valley.

1.2 Objectives

The specific objectives of the study are:

- To compare the selected small-scale irrigated schemes using comparative performance indicators;
- To evaluate the performance of selected small-scale irrigated farms in relation to water balance ratios (application, storage and distribution efficiencies); and
- To generate baseline information for further performance evaluation.

2 LITERATURE REVIEW

2.1 Irrigation

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).

2.1.1 Perspectives and objectives of irrigation

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 % of gross agricultural output (FAO, 1989).

Many countries depend on surface irrigation to grow crops for food and fiber. Without surface irrigation their agricultural production would be drastically lower and problems of unreliable food supply, insufficient rural income and unemployment would be widespread. Although precise data are lacking, estimation of surface irrigation accounts for some 80 to 90 percent of the total

260 million hectares of irrigated land worldwide, mainly in developing countries in the tropics and sub-tropics, where hundreds of millions of farmers depend on surface irrigation to grow their crops (Jurriens et al, 2001).

The method, frequency and duration of irrigations have significant effects on crop yield and farm productivity. For instance, annual crops may not germinate when the surface is inundated causing a crust over the seedbed. After emergence, inadequate soil moisture can often reduce yields, particularly if the stress occurs during critical periods. Even though the most important objective of irrigation is to maintain the soil moisture reservoir, how this is accomplished is an important consideration. The technology of irrigation is more complex than many appreciate. It is important that the scope of irrigation science is not limited to diversion and conveyance systems, nor solely to the irrigated field, nor only to the drainage pathways. Irrigation is a system extending across many technical and non-technical disciplines. It only works efficiently and continually when all the components are integrated smoothly (FAO, 1989).

FAO (1989) outlined the problems irrigated agriculture may face 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 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 (FAO, 1989).

2.1.2 Water resources and irrigation development of Ethiopia

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

The Ethiopian plateau is the source of the Abay, Awash, Tekeze, Mereb, Baro-Akobo and Omo rivers that flow to the west and southwest (Appendix B-1). The Baro-Akobo basin is potentially the largest possible irrigable area (about 483 thousand hectares) though only a negligible portion of it has been developed probably because of the large investment cost required and its distance from the central market, which makes it less favorable for commercial agriculture. Awash River is the only river extensively used for commercial plantations of industrial and horticultural. Out of the total irrigated area of about 161,125 ha, over 43% is found in the Awash River basin. The remaining potential of the Awash River for irrigated agriculture is in the order of 136,220 ha (McCornick et al, 2003).

2.1.3 Definition of small scale and large scale irrigation

The first question in any discussion of irrigation, as stated by Turner (1994) is the definition. Certainly the application of water to plants is irrigation. There could be great differences between countries and agencies over what is meant by “small”. In fact, small according to the Indian definition is regarded as large in Africa. Turner (1994) points out that irrigation systems can be classified according to size, source of water, management style, degree of water control, source of innovation, landscape niche or type of technology. Most authors, however, agree that concepts of local management and simple technology should be combined with size, and the best working definition seems to be that used by the UK Working group on Small Scale Irrigation (SSI): small scale irrigation is ‘Irrigation, usually on small plots, in which farmers have the major controlling influence and using a level of technology which the farmers can effectively operate and maintain’. There is also a case for using the term ‘farmer-managed irrigation systems’ (FMIS), as used by the International Irrigation Management Institute (IIMI), which removes the confusion with authority-managed small-scale irrigation.

According to Jorge (1993) irrigation system fall in two broad categories: those in which the principal management responsibility is exercised by government agencies with the farmers playing a subsidiary role, and those in which most management activities are carried out and decision made by the farmers themselves with the government providing periodic technical or logistical support. The latter category in which farmers assume the dominant role is referred to as Farmer-Managed Irrigation Systems (FMIS). In general, an important characteristic of FMIS is that the farmers also control and manage the water abstraction from its source.

Governments often classify these systems as “small-scale irrigation system” or “minor irrigation systems,” although examples of FMIS may be found with command areas of hectares. FMIS are also known as traditional, indigenous, communal or people’s systems. The precise set of activities and functions that the farmers and their organizations perform varies from country to country and from system to system.

2.1.4 Farmer Managed Irrigation System (FMIS) changing trends

Irrigation has been practiced for at least 5000 years in Egypt and China, 4000 years in India and the Tigris-Euphrates basin and 2,500 years in the central Andes. Large-scale systems were developed under state or royal patronage where there were well-organized social systems and long-term stability prevailed. But small-scale irrigation must be even older. In more recent times, major schemes were developed in India in the late 19th century, followed by other parts of Asia, Egypt and Sudan. These schemes were often seen as an ideal way to increase food production and reduce dependence on the variability of rainfall. They were also prestige developments, and later similar schemes appealed particularly to newly independent countries and attracted large amounts of foreign aid, especially in the 1960s and 1970s (Jorma, 1999).

Turner (1994) also described other reasons for the appeal of such schemes to governments and to donors. However, many problems became apparent when these large- scale schemes failed to live up to the expectations, costing far more and producing much lower crop yields than estimated and introducing many new problems while alienating the majority of farmers.

In recent years, there has been an emphasis on the concept of sustainable development, which is often incompatible with increasing river regulation. There is also now a tendency to decentralize management and encourage FMIS by rehabilitating old schemes and handing over control to the farmers involved (Jorma, 1999).

2.1.5 Importance of Farmers' Managed Irrigation System

Despite the lack of available statistic, there is no doubt about the importance of small-scale irrigation (SSI) in many developing countries.

For many farmers, irrigation is only part of their livelihood but often a very important part. Irrigated fields are usually valued very highly. Turner (1994) gave the following reasons for the importance of such FMIS: it can be used to extend the length of the growing season; and as a form of insurance so that when rains start late and upland crops are at risk, crops planted in the valley bottoms or those which receive supplementary irrigation are often the only ones to reach maturity.

Farmers are empowered since they are able to apply water when and where they need it. Capital costs are lower and local labor and skills are employed. In many cases, smallholders can be more productive with their yields and more efficient in water use than larger irrigation schemes (Jorma, 1999).

Irrigation is thus a valuable insurance. Several crops, such as tomatoes and leafy vegetable, grow far better in the dry season when they do not suffer attacks of mildew or pests prevalent in the wet season, and other crops require the lower temperatures of the dry season. There is also a major advantage in combining dry season and wet season cultivation. The latter is used for the staple crops but the area a family can cultivate is often limited by the labour required during operations like weeding. Dry season cultivation makes deficient use of labour at a less busy time of year. Much FMIS is for subsistence cultivation and improves the diet by providing a supply of fresh vegetable throughout the year, but it is also important as a source of high-value crops, providing income when access to roads and markets is possible (Turner, 1994).

There is much evidence that farmer-controlled small-scale irrigation has better performance than government-controlled small-scale systems. The substantial farmer-controlled small-scale irrigation sector that exists in many countries in Africa, often without government support, indicates that these systems are economically viable. Areas under farmer-controlled small-scale irrigation systems have grown rapidly over the past decades, and account for large and growing share of irrigated area in Sub Saharan Africa (McCornick et al, 2003).

For the most part bypassed by the green revolution and other successful innovations in agriculture production, smallholders live at or below the poverty level and are highly averse to risk; their very livelihoods are focused on keeping the margin for error as small as possible. At the same time, smallholders are capable of managing irrigation systems efficiently provided they have access to affordable technologies that are easy to operate, maintain and repair. Small-scale systems and technologies are attractive since they put the operation, maintenance and management of systems directly in the hands of the individual farmers, thus eliminating any need for centralized control or management (Jorma, 1999).

In general, according to McCornick et al (2003) all small-scale systems may have advantages over large-scale systems. These advantages include that small-scale technology can be based on farmers existing knowledge; local technical, managerial and entrepreneurial skills can be used; migration or resettlement of labour is not usually required; planning can be more flexible; social infrastructure requirements are reduced; and external input requirements are lower.

2.1.6 Purposes and need for small-scale irrigation in Ethiopia

Faced with a poverty driven depleted resource base, the risk averting strategy that has been followed by the rural community is increasing unsustainable pressure on natural resources leading to land and water depletion and degradation and/or 'forced' migrations to urban areas. In addition, the absence of off-farm income in rural areas has also contributed to the high population pressure on arable land, which leads to fast deterioration of natural resources.

This situation will remain a challenge until a high rate of agricultural transformation coupled with maximum and sustainable agricultural productivity (per unit area of land-intensification) takes off from the present crisis. Realizing the present socio-economic situations, it is evident that Ethiopia cannot meet its food security and food self-sufficiency objectives using the prevailing land and water use systems (McCornick et al, 2003).

Small-scale irrigation has been chosen by the majority of the cooperating sponsors as a strategic intervention to address food security in Ethiopia. According to Tom et al (1999), a number of factors led to this choice. The most obvious of which is that irrigation increases the potential for producing more food more consistently in the drought-prone food-insecure areas. This remains the central theme for these activities and investments.

Another factor favoring the adoption of irrigation was that irrigation was seen as a “window of opportunity” to avert the food shortage during the mid-1980s, despite decades of traditional efforts at promoting SSI.

Getting good statistics on small-scale irrigation, which also includes traditional schemes, is understandably difficult. At present, the figures most frequently cited estimate a total of approximately 65,000 hectares in Ethiopia. These same documents, however, raise the issue of the need for rehabilitation and upgrading many of these schemes. These figures are in sharp contrast to the widely cited overall potential for irrigation throughout the country, including small, medium and large-scale irrigation, which is thought to be possible in the ranges of 1.8 to 3.4 million hectares, of which anywhere from 180,000 to 400,000 hectares are considered potentially developable as small-scale themes (Tom et al, 1999).

Appendix B-2 provides an overview of present reference data regarding the scope for small-scale irrigation in Ethiopia. This kind of data and information is particularly important for understanding sector development options and policy. It can be a real constraint if the data is un-clear, extremely varied and considered unreliable. This information does, however, serve to put the consideration of small-scale irrigation as a food security strategy into perspective. The present levels of total area estimated to be under SSI is currently less than one percent of the total area currently being farmed. Furthermore, there is a need to know the area of the food insecure regions in the country; what percentage of the existing SSI is within these areas; and what percentage of the projected potential area for small-scale irrigation is within these foods insecure woredas. A similar analysis could be carried out on the basis of population and small-scale irrigation users.

2.1.7 Traditional small-scale irrigation innovations

In Ethiopia, irrigation schemes are classified into small, medium and large scale. Small-scale schemes are those covering an irrigated area of less than 200 hectares and growing primarily subsistence crops. Small irrigation schemes serve mainly to supplement rainfall and provide a greater degree of security to peasant farmers (McCornick et al, 2003). Because of increasing trend of population growth in the last six decades, (from 17 million in 1940 to 63 million in 2000) and increased exploitation of land resources, the balance of water resources has also been negatively affected. Although traditional small-scale irrigation practices existed in a few places, scaling-up activities must have started since the 1960s. The traditional irrigation practices by the farmers have some setbacks like:

- High labour requirement to build canals,
- Loss of productive land due to soil and stone ridging as well as tree cutting for construction purposes,
- Gully formation as a result of deep canals,
- Lack of water control to each canal resulting in poor water distribution to the stakeholders, and

- Because of the lack of extension advice on water management, the impact from such practices has been small and should be improved through improvement of the technologies.

However, farmers growing some high value cash crops and living near market centers use small pumps and generators to raise water to higher points for gravity application. Out of necessity, farmers adopt the principle of irrigation from their relatives and neighbors. Some farmers have adopted irrigation practice provided water is available.

Jorma (1999) discussed further on the problems faced by the SSI in Ethiopia and lists some of them as follows:

- In a number of instances, SSI development was almost exclusively focused on the operations associated with constructing the head works and primary canal.
- Schemes are not designed with feasible command areas that justify the capital costs of the major head works and primary canal.
- Almost everywhere, SSI activity designers and planners are faced with a lack of good data on the hydrology of the stream/river system that will be their water source and on the local weather and climate conditions.
- In remote rural areas of Ethiopia, Meteorological stations are almost non-existent.
- SSI schemes operating on the basis of uncertain data regarding water supply will be more severely affected by any losses to net water availabilities, including leakage within the system, evaporation from surface waters (of particular concern with reservoirs) and a poor grasp

of proper irrigation water management by the Development Agents (DA) and the farmers.

2.2 Performance evaluation of small-scale irrigation

The principal objective of evaluating surface irrigation systems is to identify management practices and systems that can be effectively implemented to improve the irrigation efficiency. Evaluations are useful in a number of analyses and operations, particularly those that are essential to improve management and control. Evaluation data can be collected periodically from the system to refine management practices and identify the changes in the field that occur over the irrigation season or from year to year (FAO, 1989).

The performance of any irrigation system is the degree to which it achieves desired objectives. As many FMIS do not perform as well as they should, there is a need to identify the areas in which they fall short of their potential. It is therefore important to measure and evaluate their success or failure objectively and identifies specific areas in need of improvement (Jorge, 1993).

The evaluation of surface irrigation at field level is an important aspect of both management and design of the system. Field measurements are necessary to characterize the irrigation system in terms of its most important parameters, to identify problems in its function, and to develop alternative means for improving the system (FAO, 1989).

Public agencies in many developing countries want to assist farmer-managed irrigation systems improve their performance through better management. And, better management is dependent upon appropriate methods and measures by which system performance can be evaluated relative to the management objectives (Oad & Sampath, 1995). Hence, reliable measures of system performance are extremely important for improving irrigation policy making and management decisions.

The development potential for small-scale irrigation seems attractive in view of cost effectiveness, well-focused target group and its sustainability through empowerment of the beneficiaries. However, experience has shown that there are still considerable constraints and set backs that hinder the introduction of small-scale irrigation.

2.2.1 Performance gaps existing in irrigation management

Performance is assessed for a variety of reasons: to improve system operations; to assess progress against strategic goals; as an integral part of performance-oriented management, to assess the general health of a system; to assess impacts of interventions; to diagnose constraints; to better understand determinants of performance; and to compare the performance of a system with others or with the same system over time. The type of performance measures chosen depends on the purpose of the performance assessment activity (Molden et al., 1998).

There are four potential kinds of performance gaps that can occur with irrigation systems (Douglas and Juan, 1999).

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

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

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

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

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

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

- Leakage from unlined canals or from breakages in the canal system; and

- Faulty use of irrigation water (over-watering in flood irrigation regimes).

Water lost to the system has a number of serious implications and is a classical dilemma of irrigation technology. Presuming a reasonable match of available water to crop water requirements and total command areas, water losses will lead to diminished production increases because there will not be enough water to irrigate the entire planned command area. Over-watering – using more water than is required for satisfactory crop production can cause the same effect, exacerbating the challenge of meeting the needs of both “head and tail-enders” within the irrigated perimeter. It may also lead to inefficient use of fertilizers and over-leaching of soils, or creating proper conditions for pests, thereby reducing crop productivity and leaving soils more degraded.

2.2.2 Indicators of irrigation performances

It is useful to consider an irrigation system in the context of nested systems to describe different types and uses of performance indicators (Small and Svendsen, 1992). An irrigation system is nested within an irrigated agricultural system, which in turn can be considered part of an agricultural economic system. For each of the systems, process, output, and impact measures can be considered. Process measures refer to the processes internal to the system that lead to the ultimate output, whereas output measures describe the quality and quantity of the outputs where they become available to the next higher system (Molden et al, 1998).

An irrigation system, consisting of a water delivery and a water use sub-systems, can be conceptualized to have two sets of objectives. One set relates to the outputs from its irrigated area, and the second set relates to the performance characteristics of its water delivery system (Oad and Sampath, 1995).

Bos (1997) summarizes the performance indicators currently used in the Research Program on Irrigation Performance (RPIP). Within this program field data are measured and collected to quantify and test about 40 multi-disciplinary performance indicators. These indicators cover water delivery, water use efficiency, maintenance and sustainability of irrigation, environmental aspects, socio-economics and management. He also noted that it is not recommended to use all described indicators under all circumstances. The number of indicators you should use depends on the level of detail with which one needs to quantify (e.g., research, management, information to the public) performance and on the number of disciplines with which one needs to look at irrigation and drainage (water balance, economics, environment, management).

2.2.3 Properties of performance indicators

A true performance indicator includes both an actual value and an intended value that enables the assessment of the amount of deviation. It further should contain information that allows the manager to determine if the deviation is acceptable. Some of the desirable attributes of performance indicators suggested by Bos (1997) are:

Scientific basis: the indicator should be based on an empirically quantified, statistically tested causal model of that part of the irrigation process it describes.

The indicators must be quantifiable: the data needed to quantify the indicator must be available or obtainable (measurable) with available technology. The measurement must be reproducible.

Reference to a target value: this is, of course, obvious from the definition of a performance indicator. It implies that relevance and appropriateness of the target values and tolerances can be established for the indicator. These target values and their margin of deviation should be related to the level of technology and management (Bos et al, 1991).

Provide information without bias: ideally, performance indicators should not be formulated from a narrow ethical perspective. This is, in reality, extremely difficult as even technical measures contain value judgments.

Ease of use and cost effectiveness: particularly for routine management, performance indicators should be technically feasible, and easily used by agency staff given their level of skill and motivation. Further, the cost of using indicators in terms of finances, equipment, and commitment of human resources, should be well within the agency's resources.

2.3 Comparative performance indicators

With the many variables that influence performance of irrigated agriculture, including infrastructure design, management, climatic conditions, price and availability of inputs, and socioeconomic settings, the task of comparing performance across systems is formidable. However, if we focus on commonalties of irrigated agriculture—water, land, finances, and crop production—it should be possible to see, in a gross sense, how irrigated agriculture is performing within various settings (Molden et al, 1998).

An approach to cross-system comparison is to compare outputs and impacts of irrigated agriculture. "External" indicators are used to relate outputs from a system derived from the inputs into that system. They provide little or no detail on internal processes that lead to the output. For example, the critical output of an irrigation system is the supply of water to crops. This output in turn is an input to a broader irrigated agricultural system where water combined with other inputs, leads to agricultural production. As irrigated agriculture always deals with water and agricultural production it should be possible to develop a set of external indicators for cross-system comparison.

2.3.1 Purposes of comparative performance indicators

The purpose of such study, suggested by Molden et al (1998), is to present and apply a set of external and other comparative performance indicators that will allow for comparative analysis of irrigation performance across irrigation systems. The indicators reveal general notions about the relative health of the irrigation system, yet they are not too data-intensive to discourage widespread and regular application. Such a set of indicators potentially has several purposes.

The indicators will allow for comparison between countries and regions, between different infrastructure and management types, and between different environments, and for assessment over time of the trend in performance of a specific project. They will allow an initial screening of systems that perform well in different environments, and those that do not. They will allow for both assessing impact of interventions and managers to assess performance against strategic, long-term objectives.

IWMI's minimum set of external indicators was originally presented by Perry (1996). For more information about these indicators see Appendix A. The indicators have been widely field-tested and slightly amended. The intent of presenting this set of indicators is to allow for cross-system performance. Some of the features of the indicators are the following (Molden et al., 1998):

- The indicators are based on a relative comparison of absolute values, rather than being referenced to standards or targets.
- The indicators relate to phenomena that are common to irrigation and irrigated agricultural systems.

- The set of indicators was small, yet reveals sufficient information about the output of the system.
- Data collection procedures are not too complicated or expensive.
- The indicators relate to outputs and are bulk measures of irrigation and irrigated agricultural systems, and thus provide limited information about internal processes.

This set of indicators is designed to show gross relationships and trends and should be useful in indicating where more detailed study should take place. For instance, where a project has done extremely well, or where dramatic changes have taken place. This approach differs from that of using ratios of actual to target in that the interpretation of these ratios relative to performance is not always clear (e.g., if the target value is 1, is 0.9 better than 1.1?). A relative comparison of values at least allows us to examine how well one system is performing in relation to others. And, if we have enough samples, this approach may ultimately allow us to develop standards and targets. The main audience for these external indicators comprises policy makers and managers making long-term and strategic decisions, and researchers who are searching for relative differences between irrigation systems while the main audience for internal indicators comprises irrigation system managers interested in day-to-day operations where ratios of actual to target values may be quite meaningful.

2.4 Irrigation water use efficiencies

Irrigation efficiency is the ratio between the volume used by plants throughout the evapotranspiration process and the volume that reaches the irrigation plots and indicates how efficiently the available water supply is being used, based on different methods of evaluation (Michael, 1997). The designs of the irrigation system, the degree of land preparation, and the skill and care of the irrigator are the principal factors influencing irrigation efficiency. Efficiency in the use of water for irrigation consists of various components and takes into account losses during storage, conveyance and application to irrigation plots. Identifying the various components and knowing what improvements can be made is essential to making the most effective use of this vital but scarce resource.

There are several publications describing the methods and procedures for evaluating surface irrigation systems. The data analysis depends somewhat on the data collected and the information to be derived.

Among the factors used to judge the performance of an irrigation system or its management, the most common are efficiency and uniformity (FAO, 1989). These parameters have been subdivided and defined in a multitude of ways as well as named in various manners. There is not a single parameter, which is sufficient for defining irrigation performance and according to Lesley (2002) the measure of irrigation efficiency depends on the area of interest. Ultimately, the measure of performance is whether or not the system promoted production and profitability on the farm.

Kloezen and Garces-Restrepo (1998) reviewed different literatures and summarizes that process indicators help system managers to monitor the quality of daily and seasonal operational performance. They, however, do not allow assessing the importance of irrigation in a given system, at different system levels, in a given season, and with a specific water source relative to other systems, levels, seasons, or irrigation sources. Numerous studies focus on the definition of a number of process indicators.

Common indicators defined in the literature include:

- Conveyance, distribution, field and application, and project efficiencies;
- Reliability and dependability of water distribution;
- Equity or spatial uniformity of water distribution; and
- Adequacy and timeliness of irrigation delivery

According to Molden et al (1998), much of the work to date in irrigation performance assessment has been focused on internal processes of irrigation systems. Many internal process indicators relate performance to management targets such as timing, duration, and flow rate of water; area irrigated; and cropping patterns. A major purpose of this type of assessment is to assist irrigation managers to improve water delivery service to users. Targets are set relative to objectives of system management, and performance measures tell how well the system is performing relative to these targets.

According to James (1988), the performance of a farm irrigation system is determined by the efficiency with 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 said that irrigation efficiency indicates how efficiently the available water supply is being used, based on different methods of evaluation. The objective of these efficiency concepts is to show where improvements can be made, which will result in more efficient irrigation.

Irrigation efficiencies can be measured in many ways and also vary in time and management (Roger et al, 1997). Very "efficient" system by some definitions can be very poor performers by other definition. Lesley (2002) supplemented this idea and explained it as the public's perception of irrigation efficiency is focused mostly on water use, whereas farmer's perception relates more to production. For this reason, it is unrealistic to use one all-encompassing definition. For instance, where water is very short, efficiency may be measured as crop yield per cubic meter of water used, or profit per millimeter of irrigation. It depends what you want to know.

Michael (1997) and Jurriens et al (2001) put as a remark that the primary performance indicators are: storage efficiency, application efficiency and distribution uniformity.

2.4.1 Application efficiency

After the water reaches the field supply channel, it is important to apply the water as efficiently as possible. A measure of how efficiently this is done is the application efficiency. One very common measure of on farm irrigation efficiency is application efficiency. That asks how much of the water applied to the crop is actually used for crop growth or other beneficial uses?

The definition of application efficiency, E_a, has been fairly well standardized as:

$$E_a = \frac{Depth\ of\ water\ added\ to\ the\ root\ zone}{Depth\ of\ water\ applied\ to\ the\ field} \text{.......................} \quad [2.1]$$

According to Jurriens et al (2001), application efficiency is a common yardstick of relative irrigation losses and this definition is valid for all situations and all irrigation methods. Losses from the field occur as deep percolation and as field tail water or runoff and reduce the application efficiency. To compute E_a it is necessary to identify at least one of these losses as well as the amount of water stored in the root zone. This implies that the difference between the total amount of root zone storage capacity available at the time of irrigation and the actual water stored due to irrigation be separated, i.e. the amount of under-irrigation in the soil profile must be determined as well as the losses (FAO, 1989).

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

Lesley (2002) explained and defined the situation of application efficiency with time and event specific and the equation could be used for a single irrigation event or more as a term reflecting seasonal performance. The difference in how it is used can be quite dramatic. For example, the first irrigation event using furrow irrigation can have a very low application efficiency if the length of run is long, furrows are freshly corrugated, stream size is wrong or for several other reasons. If irrigations are too close together, or the amount of water applied is too high, the application efficiency will be lower than it could be. This will indicate low irrigation efficiency, showing that water is being wasted as deep percolation. According to him, the purpose of application efficiency was to help estimate the gross irrigation requirement once the net irrigation need was determined and vice versa.

Application efficiency does not show if the crop has been under-irrigated. However according to Roger et al (1997), it is possible to have high application efficiency and 50-90% can be used for general system type comparison. FAO (1989) reported that the attainable application efficiency according to the US (SCS) ranges from 55%-70% while in ICID/ILRI this value is about 57%. Lesley (2002) suggested that it could be in the range of 50-80%.

In general, according to Michael (1997) water application efficiency decrease as the amount of water applied during each irrigations increase.

2.4.2 Storage efficiency

Small irrigations may lead to high application efficiencies, yet the irrigation practice may be poor. The concept of water storage efficiency is useful in evaluating this problem. Jurriens et al (2001) express adequacy of irrigation turn in terms of storage efficiency and the purpose of an irrigation turn is to meet at least the required water depth over the entire length of the field. Conceptually, the adequacy of irrigation depends on how much water is stored within the crop root zone, losses percolating below the root zone, losses occurring as surface runoff or tail water the uniformity of the applied water, and the remaining deficit or under-irrigation within the soil profile following an irrigation.

The water storage efficiency refers how completely the water needed prior to irrigation has been stored in the root zone during irrigation. The water requirement efficiency,, E_r, which is also commonly referred to as the storage efficiency is defined as (Mishra and Ahmed, 1990; FAO, 1989):

$$E_r = \frac{Volume\ of\ water\ added\ to\ the\ root\ zone\ storage}{Potential\ soil\ moisture\ storage\ volume} \qquad \text{..................[2.2]}$$

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

Water stored in the root zone is not 100% effective (FAO, 1992). Evaporation losses may remain fairly high due to the movement of soil water by capillary action towards the soil surface. Water lost from the root zone by deep percolation where groundwater is deep. Deep percolation can still persist after attaining field capacity. Depending on weather, type of soil and time span considered, effectiveness of stored soil water might be as high as 90% or as low as 40%.

2.4.3 Distribution efficiency

When a field with a uniform slope, soil and crop density receives steady flow at its upper end, a waterfront will advance at a monotonically decreasing rate until it reaches the end of the field (FAO, 1989). Roger et al (1997) explained that water lost to percolation below the root zone due to non-uniform application or over-application water run off from the field all reduces irrigation efficiencies. To get a complete picture of an irrigation performance you need to know more indicators than just discussed above, because these are averages taken over the entire length of the field or furrows.

Although different cases might produce the same results for application and storage efficiencies, their distribution patterns could differ. One indicator used to represent the pattern of the infiltrated depths along the field length is the distribution uniformity (DU), which is defined as the minimum infiltrated depth divided by the average infiltrated depth (Jurriens et al, 2001). This is given in the form:

$$DU = \frac{Minimum \quad depth}{Average \quad depth} \qquad \text{..........[2.3]}$$

Application efficiency is concerned with the distribution of water over the actual field. Jurriens et al (2001) proposed that distribution uniformity be defined as the average infiltrated depth in the low quarter of the field divided by the average infiltrated depth over the whole field. This term can be represented by the symbol, DU. The same authors also suggest 'absolute distribution uniformity' DU which is the minimum depth divided by the average depth. Thus, the evaluator can choose one that fits his/her perceptions but it should be clear as to which one is being used (FAO, 1989).

The uniformity of application is evaluated using the Christianson Uniformity coefficient (Jensen, 1983; Michael, 1997; Jurriens et al, 2001). This is given as:

$$C_u = 100 \times \left(1.00 - \frac{\sum |d|}{n\overline{\mathrm{X}}} \right), \qquad d = \mathrm{X}_i - \overline{\mathrm{X}} \quad \text{....................[2.4]}$$

Where:

C_u = Christianson Uniformity Coefficient;

d = deviation of observation from the mean;

n = number of observations;

$\overline{\mathrm{X}}$ = Average depth infiltrated;

X_i = Depth infiltrated at observation point *i.*

Distribution uniformity describes how evenly irrigation is applied to the crop. This needs to be measured in the field. FAO (1992) suggested that having average rotational supply with management and communication adequate Distribution Efficiency DU of 65% as “sufficient” and DU of 30% as “poor”.

2.4.4 Combined measures of efficiency

Application efficiency is the most important in terms of design and management since it reflects the overall beneficial use of irrigation water. Design and management strategy will be proposed in which the value of application efficiency is maximized subject to the value of requirement efficiency being maintained at 95-100 percent. This approach thereby eliminates storage efficiency from an active role in surface irrigation design or management and simultaneously maximizes application uniformity. If the analysis tends to maximize application efficiency, distribution uniformity is not qualitatively important and may be used primarily for illustrative purposes. Of course, some may prefer performance discussed in terms of uniformity or be primarily involved in systems where under irrigation is an objective or a problem. For these cases, uniformity is still available. The assumption of maximization of application efficiency in effect states that losses due to deep percolation or runoff are equally weighted (FAO, 1989).

A system with low distribution uniformity cannot have high application efficiency and still adequately water crops (Lesley, 2002). If the application efficiency is greater than the distribution uniformity, you can be pretty sure the crop has been under-watered. If the application efficiency is less than the distribution uniformity you can be pretty sure the crop was over-watered. This conclusion is also supported by Roger et al (1997) as it is possible to have a high application efficiency but have the irrigation water so poorly distribute that crop stress exists in areas of the field.

2.4.5 Irrigation scheduling

The purpose of irrigation scheduling is to determine the exact amount of water to apply to the field and the exact timing for application. The amount of water applied is determined by using a criterion to determine irrigation need and a strategy to prescribe how much water to apply in any situation. Hence the importance of irrigation scheduling is that it enables the irrigator to apply the exact amount of water to achieve the goal. This increases irrigation efficiency.

Irrigation scheduling is the process of determining when to irrigate and how much water to apply per irrigation. Proper scheduling is essential for the efficient use of water, energy and other production inputs, such as fertilizer. It allows irrigations to be coordinated with other farming activities including cultivation and chemical applications. Among the benefits of proper irrigation scheduling are: improved crop yield and/or quality, water and energy conservation, and lower production costs (James, 1988).

FAO (1989) explained that when surface irrigation methods are used, however, it is not very practical to vary the irrigation depth and frequency too much. In surface irrigation, variations in irrigation depth are only possible within limits. It is also very confusing for the farmers to change the schedule all the time. Therefore, it is often sufficient to estimate or roughly calculate the irrigation schedule and to fix the most suitable depth and interval: to keep the irrigation depth and the interval constant over the growing season.

Important soil characteristics in irrigated agriculture include: (1) the water-holding or storage capacity of the soil; (2) the permeability of the soil to the flow of water and air; (3) the physical features of the soil like the organic matter content, depth, texture and structure; and (4) the soil's chemical properties such as the concentration of soluble salts, nutrients and trace elements (FAO, 1989).

Normally farmers will use their own experience and indicators (wilting characteristics, soil dryness) to determine when to irrigate (Smith and Munoz, 2002). According to them this has proved not very accurate and a “scientific” advice to farmers on when to irrigate can lead to considerable water savings and to a more rational planning of water distribution.

Of several methods to determine *when to irrigate*, “Water indicator” and “Soil budget” are the two widely used techniques (James, 1988). The water budget technique is based on the equation:

$$I = ET - P_e + RO_i + DP_i + L + D_{rz}(q_f - q_i) \quad [2.5]$$

Where: *I= Irrigation requirement; ET= evapotranspiration;* P_e*= effective precipitation (cm);* RO_i*,= runoff due to irrigation (cm);* DP_i*= deep percolation due to irrigation (cm);* D_{rz}*= depth of root zone (cm);* Q_f *&* Q_i *= final and initial soil moisture contents.*

Water budget method is more commonly applied these days. The large amount of studies and research on water crop requirements has lead to more accurate ET crop estimation from weather data and has made the ET_o based on water balance method the most convenient and reliable way to predict when to irrigate (Smith and Munoz, 2002).

Soil based irrigation scheduling involves determining the current water contents of the soil, comparing it to a predetermined minimum water content and irrigation to maintain soil water contents above the minimum level. Soil indicators of when to irrigate also provide data for estimating the amount of water to apply per irrigation.

According to Mishra and Ahmed (1990), irrigation interval is calculated by the formula:

$$Irrigation\ \ Interval = \frac{AMD}{ET_C} \qquad \text{[2.6]}$$

Where: AMD = allowable soil moisture depletion, cm

ET_C = daily water use, cm/day

Depth of irrigation application is the depth of water that can be stored within the root zone between field capacity and the allowable level the soil water can be depleted for a given crop, soil and climate. It is equal to the readily available soil water over the root zone (James, 1988).

How much water to apply is depending on the irrigator's strategy. A critical element is accurate measurement of the volume of water applied or the depth of application. A farmer cannot manage water to maximum efficiency without knowing how much water applied. Also, uniform water distribution across the field is important to derive the maximum benefits from irrigation scheduling and management. Accurate water application prevents over-or under-irrigation.

According to FAO (1989), the total available water (TAW), for plant use in the root zone is commonly defined as the range of soil moisture held at a negative apparent pressure of 0.1 to 0.33 bar (a soil moisture level called 'field capacity') and 15 bars (called the 'permanent wilting point'). The TAW will vary from 25 cm/m for silty loams to as low as 6 cm/m for sandy soils.

The net quantity of water to be applied depends on magnitude of moisture deficit in the soil, leaching requirement and expectancy of rainfall. When no rainfall is likely to be received and soil is not saline, net quantity of water to be applied is equal to the moisture deficit in the soil, i.e. the quantity required to fill the root zone to field capacity. The moisture deficit (*d*) in the effective root zone is found out by determining the field capacity moisture contents and bulk densities of each layers of the soil (Mishra and Ahmed, 1990).

$$d = \sum_{i=1}^{n} \frac{(FC_i - PW_i)}{100} \times As_i \times D_i \quad \text{[2.7]}$$

Where: *FC_i = field capacity of the i^{th} layer on oven dry weight basis*

PW_i = actual moisture contents of the i^{th} layer on oven dry weight basis

Asi= apparent specific gravity of the ith layer

Di = depth of ith layer and, n=number of layers in the root zone

According to Jurriens et al (2001), the required depth (*d)* is not usually the same as the applied depth (D_a), *which* is equal to the applied volume divided by the area. If the applied depth infiltrates the field area entirely, the applied depth equals the average infiltrated depth (D_{ave}). Jurriens et al (2001) further discussed on that, the average depth of water that is actually stored in the target root zone D_{req} is the storage depth (D_s). When the target zone is entirely filled, D_s will equal D_{req}. If $D_s < D_{req}$, then there is under-irrigation and if $D_s > D_{req}$, then there is deep-percolation.

2.5 Soil water availability

Soil water availability refers to the capacity of a soil to retain water available to plants. After heavy rainfall or irrigation, the soil will drain until field capacity is reached. Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased. The total available water in the root zone is the difference between the water content at field capacity and wilting point (Allen et al, 1998):

TAW = 1000(è$_{FC}$ - è$_{WP}$) Z_r ……………………………………………………………[2.8]

Where: TAW the total available soil water in the root zone [mm],

è$_{FC}$ the water content at field capacity [m^3 m^{-3}],

è$_{WP}$ the water content at wilting point [m^3 m^{-3}],

Z_r is the rooting depth [m].

TAW is the amount of water that a crop can extract from its root zone, and its magnitude depends on the type of soil and the rooting depth. Typical ranges for field capacity and wilting point are listed in Appendix C for various soil texture classes.

The fraction of TAW that a crop can extract from the root zone without suffering water stress is the readily available soil water:

RAW = ñ TAW ……………………………………………………………………………[2.9]

Where:

RAW the readily available soil water in the root zone [mm], ñ average fraction of Total Available Soil Water (TAW) that can be depleted from the root zone before moisture stress (reduction in ET) occurs [0-1].

If there are plants growing on the soil, the moisture level continues to drop until it reaches the "permanent wilting point" (PWP). Soil moisture content near the wilting point is not readily available to the plant. Hence the term "readily available moisture" has been used to refer to that portion of the available moisture that is most easily extracted by the plants, approximately 75% of the available moisture. After that, the plants cannot absorb water from the soil quickly enough to replace water lost by transpiration (ICE, 1983).

3 MATERIALS AND METHODS

3.1 General Descriptions of the Study Area

In order to illustrate the potential use of irrigation performance indicators in evaluating efficiency of irrigation systems, two schemes in the Awash drainage basin were considered. The criteria for consideration of the two irrigation projects were based on the proximity to Melkassa Research Center, availability of secondary data and organizational set up of the irrigation projects.

3.1.1 The Awash River Basin

The Awash River starts from the Ginchi Watershed in the central highlands of Ethiopia and flows towards Djibouti with a total length of 1,200 km. The basin is divided into Upper and Middle Valley and Lower Plains. The Awash basin covers a total area of 110,000 km^2 of which 64,000 km^2 form the Western catchment. They drain into the main river or its tributaries. The remaining 46,000 km^2, most of which comprises the eastern catchments, drain into a desert area and do not contribute to the main river flow. The basin includes mainly the Afar, Oromiya and Amhara regions including the area of the Addis Ababa city Administration and Dire Dawa council. Four zones of Oromiya, three zones of Amhara and most districts of Afar, Addis Ababa and Dire Dawa fall partly or wholly within the Awash River basin, or have significant proportion of their area falling inside the basin.

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

The irrigation potential for the Awash basin is estimated to be 206,000 ha. But so far only 42.7% (88,000 ha) have been developed. Out of these, 26.5% (23,306 ha) are under traditional and modern small-scale irrigation. The remaining 73.5 % (64.694 ha) are developed under state farms and private investors. These include several agro-industries such as sugar factories and horticultural farms, ranches and cattle fattening, resort areas and other small industries (McCornick, 2003).

Based on its physical and climatological characteristics, the basin is divided into the following four zones: the upper basin, the upper valley, the middle valley and the lower valley (Tena, 2002).

The upper valley of the Awash River basin, where the study area is located, is the area between the Koka dam and Awash station in which the river traverses some 300 km. The altitude ranges from 1000-2000 m. a.s.l; and annual rainfall varies from 600-800 mm. The dominant agriculture is grazing and irrigated cash crops.

3.1.2 Batu Degaga Irrigation Project

Establishment: Prior to the development of the Batu Degaga irrigation project, the life of the farmers in the vicinity were relied on the production of rain fed crops and livestock. The agricultural production was not satisfactory due to the fact that the rainfall is too low for such arid environment. The farmers were forced to move and work in the neighboring state farms as daily laborers and the government, for their survival, had to feed some of the farmers. Considering the seriousness of the problem and to eradicate it from the area, the irrigation project was established by World Vision Ethiopia in 1992 (ASE, 1994). Initially the area was designed to cover gross command area of 165 ha and total irrigable land of 140 ha.

Up on the development of the project, each farmer was cultivating his own land separately. This has created disputes among farmers. To settle the dispute, it was founded to set up the organizational rule. This organization rule was established for the Batu Degaga water users association in January 27, 1993.

History and organizational setup of the project: Following the establishment of the Farmers' Water Users Association, which was lead by the selected administrative committee from the irrigation project, out of the 140 ha land, only 100 ha had been cultivated. Even though the association had tried to produce crops (with the support of the World Vision and Ministry of Agriculture) due to the lack of experience and motivation, the project could not be successful as anticipated. The numbers of farmers participating in the project activities were varying from year to year. It, however, finally settled with 120 members.

World Vision Ethiopia, in 1996, transferred the project management to the association with the assumption that the association can cover the expenditure and run the project by itself. From then onwards, the Ministry of Agriculture (MoA) has taken the responsibility and assigned one Development Agent (DA) to assist, organize the farmers and to create a link between the association and MoA, funding agency and other organizations. The association got legalized in 1999 and this created for a better acceptance by National and Regional Governmental organizations and NGOs. In the same year it got the legality, it started to produce vegetable crops well. Unfortunately, due to the unexpected rain and flood from upland, the cultivated crops were damaged and the project could not cover its electric consumption so that the power was disconnected by the year 2001.

During 2001, 2002, and part of 2003 calendar years, the project was completely closed, resulting in severe poverty and even loss of several farmers' life due to famine and starvation. In January 2003 the Woreda Bureau of Agriculture had taken the initiative and organized a committee to consult different respective governmental and non-governmental organizations on how to rehabilitate the project. Then World Vision covered the electric fee with the agreement that the expense covered should be taken as a credit loaned to the irrigation project association.

Feeling the problem the farmers faced in the past, they were reorganized. The area reduced to only 60 ha due to pump inefficiency. Unfair seasonal contribution of money, which was equal to all regardless of size of land holding was changed so that every farmers pay according to the area he irrigated. More over water wastage reduced substantially. Currently the association has 122 members, having 0.5 hectares of irrigable land on average and a total of 60 ha irrigable land.

Location and topography: Batu Degaga Irrigation Project is located in the Upper Valley of Awash River Basin near Sodore, around 7 km on the left side of the road from Melkassa town to Sodore. Geographically the farm is located at a latitude of 8^0 25 North and longitude of 39^0 25 East in Eastern Shoa administrative Region. The scheme is bounded by the Awash River in the south, Tibila Estate farm in the east and extensive rain fed agricultural land in the north and west. The elevation of the project area is around 1350 meters above sea level (Appendix I).

The land of irrigation project is characterized by plain land of very gentle slope, which is suitable for surface irrigation. The total developed irrigable area of the project is 140 ha and out of this, 60 ha is under cultivation and 122 farmers are beneficiaries.

Climate: based on the climatological data of Melkassa Research Center, the nearest weather station, the rainfall in the region can be estimated to vary between 700 mm to 860 mm mainly received from June to September followed by a distinct dry spell up to January. This is often preceded by secondary or small rainy season running from February to April. The potential evapotranspiration of the area reaches as high as 2060 mm per year (Appendix G-1).

The average monthly minimum and maximum temperature in the project area is in the order of 11^{o}C and 33^{0}C, respectively. Generally the area is belonging to semi-arid drought prone region of the country.

Water sources and abstraction: The irrigation project draws water from Awash River that has regulated discharge through out the year at Koka dam. To abstract irrigation water from the river, the project has 3 electric pumps, which are operating rotationally through out the irrigation season. Pumping system comprises pump house, transformer, electric motors and main supply pipeline. The actual average discharge of the three is 85 liters per second and the maximum discharge capacity of the main canal of the Batu Degaga irrigation project is 300 liters per second.

Fig 3.1 Irrigation water abstraction at Batu Degaga

Water distribution system: the irrigation water pumped from the river is discharged to a small reservoir that is used to dissipate the energy. Then 230-meter length concrete made primary canal carries the water to secondary canals. The secondary canals having a total length of 1800 meters runs longitudinally and with the help of several turnouts along the canal distributes the water to tertiary canals laterally. Individual farmers, according to their need, construct the tertiary canals to divert water into their fields. Farmers are diverting the water through their preferred direction as long as it is suitable to provide available head to irrigate their field.

3.1.3 Doni Kombi Irrigation Project

History of establishment: Some 30 years ago, a private investor constructed a low head gravity weir in Awash River and about 3 km long main canal for the scheme. During the military regime, the land was nationalized and distributed to the peasants. Producer Cooperatives (PC) was established to administer and use the scheme. Scheme operation and maintenance was not good enough to keep it functional. After few years, it almost collapsed and stopped functioning. Almost all conveyance structures were destroyed and canals were completely silted up.

Following the downfall of military regime and dissolvent of the PC, a group of individual farmers who own land within the boundary of irrigation scheme started rehabilitating of the scheme and requested the assistance of CARE-International in Ethiopia (Non-governmental Organization) to rehabilitate the system. Following some field investigation, the request for rehabilitation was accepted in 1994 and the construction was completed in 1997 (CARE, 2001).

At the moment, one development agent (DA) has been assigned by the Woreda's Irrigation Bureau to assist, advice, organize and monitor the irrigation project activity and the farmers in the association. The association has committee selected by the members to organize the farmers and to collect money from the members.

Location: Doni irrigation project is located in the Upper Valley of Awash River Basin and 33 km North of Sodore town. Geographical location of the project is

$8^0 30^l$ N and $39^0 33^l$ E and the elevation varies from 1240 m to 1280 m above sea level. The project area lies on the left hand side of the rural road, which runs from Awash Melkassa to Nura Era state farm. The diversion work is about 1.3 km away from this road. The main canal crosses the road and the distribution canal ends about 7.3 km northeast of Doni village (Appendix I).

Climate: based on the climatological data of Nura Era State farm, the rainfall in the region can be estimated to vary between 600 mm to 700 mm mainly received from June to September followed by a distinct dry spell up to January. This is often preceded by secondary rainy season of February to April. The evapotranspiration of the area reaches as high as 1907 mm per year (Appendix G-2).

The average monthly minimum temperature of the project area is 13^oC while the average maximum is about 36^0C. Generally based on the climatological data, area is belonging to semi-arid drought prone region of the country.

Soils and topography: The area is situated on an undulating alluvial plain with open vegetation. In the area surrounding the project site gullies up to 10 m deep can be observed. The irrigation area lies between a hill to the north and Awash River to the south and southeast. The slope of the site is estimated to vary from 0.5 to 4 %. More than 95% of the command area has slope less than 3%. The land unit in Doni can be classified as flat to rolling. The land at the tail of the main canal (an area locally called Sefa Denke) is more of flat land and very suitable for irrigation. The soils are mostly medium textured which ranges from silty loam to sandy loam. The depth of the soils in the area varies from 30 cm to 100 cm.

Water sources and abstraction: The source of water for the irrigation project is the Awash River. A number of large and medium state owned commercial irrigation farms in the country are receiving water for irrigation from this river. The Awash River is diverted to the canal by constructing a diversion wall at a location where there is small natural protruding land in the river. The diverted water is then blocked by a weir near the main gate to raise the head of the water in the canal.

Fig 3.2 Diversion weir and the main canal at Doni irrigation project

3.2 Methodologies used

3.2.1 Data collection methodologies

The data collection has been carried out in collaboration with the DA of Doni and Batu Degaga Irrigation Projects assigned by the Woreda Agricultural Office. It was started in July 2003. During the reconnaissance survey, agricultural offices, sponsor organizations, professional staff, DAs and some farmers were consulted about the general conditions of small-scale irrigations. Based on the survey made and the information gathered; two irrigation projects were selected. The criteria for selection were proximity for Melkassa Research station, availability of organizational set up, nearness to weather station, and the availability of secondary data. Data collected included primary sources at field level in the irrigation project.

As much as possible, three farmers' fields were selected from the head; middle and tail water users of each irrigation projects.

3.2.1.1 Primary data collection

Primary field data collection activities included:

- Frequent field observations were made to observe and investigate the method of water applications, and practices related to water management techniques made by the assigned persons and farmers.

- Measurements of canal water flow at the diversion of Doni and pump discharge of Batu Degaga were taken frequently. Based on this average discharge coupled with the total flow time the total volume of water diverted by the irrigation scheme was estimated.

- Moisture contents of the soils of the selected irrigation fields before and after irrigations were determined by taking soil samples at different depths of the profiles.

- To determine the pH, EC_e and texture of each farmer's field, soil samples were collected periodically from different depths. And also using sampling rings undisturbed soil samples were collected and the bulk densities at different depths were determined.

- Three inches parshal flumes were constructed using sheet metal and installed at the entrance of the selected farmer's fields to measure the depth of water applied to the specific areas of fields.

Determination of the amount of water applied to the fields

To determine the amount of water applied by the farmers to their fields, a three inches (3||) *Parshal flume* was installed at the entrance of each field and frequent readings were taken. During the determination of the amount of water applied to the field, the average water depth irrigation water passing through the flume to the field and respective time intervals were recorded with the sizes of the fields being irrigated. The discharges of the water applied were taken from Table s for corresponding depths of a specific size of Parshal flume

Discharge determination

The discharges of irrigation water diverted from Awash River at the irrigation projects were determined by different methods that suit their water abstraction methods. At Batu Degaga, the discharges of each pumps were determined by *volumetric method* while the discharge of the main canal at Doni diversion weir was measured by using propeller type *current meter* (James, 1988). The diversion at Doni was cleaned and completely opened at the beginning of October 2003 and the pumps at Batu Degaga started at the same time in 2003. To calculate the total amount of water diverted to the total irrigated areas within a season, the total flow time of irrigation water in the main canal were recorded and multiplied by the respective discharges.

3.2.1.2 Secondary data collection

Secondary sources kept by the responsible bodies or officials at each irrigation project, Woreda Agricultural Offices, Irrigation Offices at Regional, Zonal, and Central levels were collected as much as possible. Furthermore, Research Centers and NGOs of the agricultural sectors were visited periodically to gather further information. The Secondary data included total yields, farm gate prices of irrigated crops, area irrigated per crop per season or per year, crop types, production cost per season or per year, incomes generated by the irrigation associations and cropping pattern. Based on the questionnaire developed interview were made to get the perception of the farmers about the water distribution with in the project. Much effort has been spent through survey and observations of different documents at different places to check the reliability and consistency of these data.

Climatic data of each irrigation projects were collected from the near by weather stations. Melkassa Research Center and Nura Era State Farms were the sources of the climatic data for Batu Degaga and Doni irrigation projects, respectively. The design documents of the irrigation projects were collected from the respective sponsor organizations and used as a source of information on the investment costs of the irrigation projects.

Crop Production data collection

One of the criteria used to select the two irrigation projects was the availability of recorded data that are used to calculate some of the performance evaluation parameters. Even if the data recorded by the projects are not complete, consistent and not supported by skilled manpower, relatively these irrigation projects were at the better position than others. The financial data used to calculate some of the parameters in this study were copied from the documents that have been audited and checked by the responsible government offices.

3.2.1.3 Laboratory analyses

Bulk densities (BD), textures, pH, EC_e, Field Capacity (FC), Permanent Wilting Point (PWP) of the soils of the selected farmers fields at different depths were determined in the laboratory. To determine these soil parameters with their respective laboratorial procedures, recommendation manuals of Kamara and Haque (1991) and Sahlemedhin and Taye (2000) were followed. Then the values of the parameters determined were applied where they are appropriate for the analyses of the study.

Gravimetric sampling for moisture content determination

Gravimetric samplings were made by collecting more than 90 soil samples from each farmer's fields with an interval of 30 cm of the soil depth up to 90 cm depth. It is presumed that this depth is deeper than the effective root zone of the irrigated vegetable crops. The maximum effective root zone of small vegetables, like onion, is 60 cm (Allen et al, 1998). The soil samples were placed in a container of known weight and then weighed. The samples were then placed in an oven heated to 105° C for 24 hours with the container cover removed. After drying, the soil and container were again weighed and the weight of water was determined. The dry weight fraction of each sample was calculated using the equation (FAO, 1989; Kamara and Haque, 1991)

$$q_w = \frac{W_w - W_d}{W_d} \times 100 \quad \text{......[3.1]}$$

Where: *è$_w$ = soil water content on a dry weight basis, %*

W_w = wet weight of the soil, gm

W_d = dry weight of the soil, gm

Then the moisture contents of the soils collected from the selected fields at different depths were determined.

3.2.2 Data analysis techniques

3.2.2.1 Crop water requirements

To estimate the crop water requirements (CWR), irrigation scheduling and irrigation water requirement (IWR) of the irrigated crops at field levels and the irrigation project as a whole the CropWat for windows (CropWat 4 Windows Version 4.2) were used. This program uses the FAO (1992) Penman-Monteith equation for calculating reference crop evapotranspiration. The determination of the CWR by this model depends on the determination of the reference evapotranspiration values using the available climatic data. The determination of IWR was carried out after estimation of effective rainfall by USDA soil conservation service method (Clarke, 1998).

The irrigation requirements of each irrigation projects were calculated with CropWat using the climatic data, cropping pattern, planting dates, and area of each crops.

3.2.2.2 Comparative Performance Indicators

The comparative performance indicators rely on the availability of secondary data. Getting complete data required to calculate all the external indicators (the nine indicators) for each small-scale irrigation project was very difficult. The types of data recorded by each irrigation projects have different natures and limited the application of all the nine parameters used in the *comparative performance indicators* developed by IWMI for the same cropping season of the two irrigation projects. Hence, to compare the two-irrigation projects, minimum sets of external indicators were applied with the available information gathered and comparative analyses were made within and across the irrigation projects.

Based on the minimum set of comparative performance indicators: evaluation of each project for individual performance, comparison of the two irrigation projects and trend of their performance were studied.

3.2.2.2.1 Evaluation of the individual irrigation projects

The four indicators in the minimum set for comparative performance indicators are *Relative Water Supply (RWS), Relative Irrigation supply (RIS), Water Delivery Capacity (WDC) and Gross return on investment (GRI).* They are meant to characterize the individual system with respect to water supply and finances (Molden et al, 1998).

Relative water supply and relative irrigation supply are used as the basic water supply indicators:

$$Relative\ \ water\ \ supply\ = \frac{Total\ \ water\ \ supply}{Crop\ \ demand}$$

……………………..[3.2]

$$Relative\ \ irrigation\ \ supply = \frac{Irrigation\ \ supply}{Irrigation\ \ demand}$$

………………………..[3.3]

Where:

Total water supply = Surface diversions plus net groundwater plus rainfall.

Crop demand = Potential crop ET, or the ET under well-watered conditions.

Irrigation supply = Only the surface diversions and net groundwater draft for irrigation.

Irrigation demand = the crop ET less effective rainfall.

Both RWS and RIS relate supply to demand, and give some indication as the condition of water abundance or scarcity, and how tightly supply and demand are matched.

The water delivery capacity (WDC) is given below:

$$Water\ delivery\ capacity(\%) = \frac{Canal\ capacity\ to\ deliver\ water\ at\ system\ head}{Peak\ consumptive\ demand} \quad ...[3.4]$$

Where:

Capacity to deliver water at the system head = the present discharge capacity of the canal at the system head, and

Peak consumptive demand = the peak crop irrigation requirements for a monthly period expressed as a flow rate at the head of the irrigation system.

WDC is meant to give an indication of the degree to which irrigation infrastructure is constraining cropping intensities by comparing the canal conveyance capacity to peak consumptive demands.

$$Gross\ return\quad on\ Investmenet\ (\%) = \frac{Production}{Cost\ of\ irrigation\quad structure}$$

....[3.5]

Where:

Production is the output of the irrigation project

Cost of irrigation infrastructure considers the cost of the irrigation water delivery system referenced to the same year as the production.

Based on the design documents of the sponsoring organization, the investment costs of the distribution systems of the respective irrigation projects were calculated and *Gross Rreturn on Investment (GRI)* was determined. Financial data were collected from the representatives of the irrigation projects and the canal capacities were measured at field level. To evaluate the *GRI*, data of gross value of output and cost of distribution system of the irrigation projects are essential. For Batu Degaga case, only one-year (2003) data of gross values of output (productions) were available but at Doni long-term yearly gross productions have been recorded by the association but for comparison purpose, only one year data was used.

3.2.2.2.2 Comparison of the two irrigation projects

In order to compare the two selected irrigation projects, the four comparative indicators were used because these “external” indicators provide the basis for comparison of irrigated agriculture performances across systems (Molden et al, 1998).

$$Output\ per\ cropped\ area = \frac{Production}{Irrigated\ cropped\ area} \qquad [3.6]$$

$$Output\ per\ unit\ command\ area = \frac{Production}{Command\ cropped\ area} \qquad [3.7]$$

$$Output\ per\ irrigation\ supply = \frac{Production}{Diverted\ irrigation\ supply} \qquad [3.8]$$

$$Output\ per\ unit\ water\ consumed = \frac{Production}{Volume\ of\ water\ consumed\ by\ ET} \qquad [3.9]$$

Where:

Production is the output of the irrigated area in terms of gross or net value of production measured at local or world prices.

Irrigated cropped area is the sum of the areas under crops during the time period of analysis,

Command area is the nominal or design area to be irrigated,

Diverted irrigation supply is the volume of surface irrigation water diverted to the command area, plus net removals from groundwater, and

Volume of water consumed by ET is the actual evapotranspiration of crops.

When only one irrigation system is considered, or irrigation systems in a region where prices are similar, production can be measured as gross value of production using local values.

The first two parameters were calculated based on the crop productions of the year 2003 (Feb to Oct) of the two projects.

Some data, like the irrigation water supply, that can be used to calculate the last two parameters needs direct field measurements for each cropping seasons otherwise long-term recorded data must be available (which was impossible in our case). So for this study these parameters were applied for 2003/2004 (Oct-Feb) cropping season only for the availability of these data through field measurements made by the researcher.

3.2.2.2.3 Trend Performances of the two irrigation projects

Within one system, comparative indicators allow to distinguish between differences in performance across seasons. If the minimum set of external indicators is disaggregated in time and space, they serve as tools for internal management of irrigation systems and for evaluating impacts of interventions (Molden et al, 1998).

These concepts were applied for the two irrigation projects. By calculating the Financial Self Sufficiency's (FSS) of each irrigation projects within a certain periods, the trend of financial performances of each irrigation project were evaluated. Based on the available data recorded, for the Batu Degaga irrigation project the FSS was computed for 11 years, while 6 years period was computed for the Doni irrigation project.

$$Financial\ self\ sufficency = \frac{Revenue\ from\ Irrigation\ Service\ fees}{Total\ O\ \&\ M\ expenditure}$$ ……….……[3.10]

Where:

Revenue from irrigation, is the revenue generated, either from fees, or other locally generated income, and

Total O & M expenditure is the amount expended locally through operation and management

3.2.2.3 Irrigation water use efficiencies

3.2.2.3.1 Farmer's field evaluation in each scheme

In order to evaluate the irrigation water use efficiency of farmers at field level and to compare each other in the same irrigation projects, three farmers were selected from each irrigation projects. These fields were selected from the head, middle and tail end water users of the irrigation projects. The assumption behind the selection criterion of the farmer's fields was that there was a tendency of the head end users to over-irrigate their crops while the tail end users were in short supply of irrigation water (Levin et al, 1998).

Infiltration of water into the furrow is the most important variable affecting the characteristics of flow in furrows. According to Michael (1997), in order to evaluate furrow irrigation performance gravimetric method of measuring soil moisture content, which was done by taking the moisture contents of the soil before and after irrigation, is more accurate but time consuming.

The parameters used to compare the efficiencies at field level were application efficiency, storage efficiency and distribution efficiency.

3.2.2.3.2 Determination of application efficiency

After determining the depth of water actually applied into the fields using a three inches Parshal flume (Mishra & Ahmed, 1990) and the depth of the water retained in the root zone of the soil based on the soil moisture contents of the soils before and after irrigation, the application efficiencies *(E_a)* of irrigation at the selected fields were calculated using equation [2.1].

The depth *(d)* of water retained in the soil profile in the root zone was determined by using the equation (Mishra and Ahmed, 1990):

$$d = \sum_{i=1}^{n} \frac{(Q_f - Q_i)}{100} \times As_i \times D_i \quad \text{......[3.11]}$$

Where:

Q_f = moisture content of the ith layer of soil after irrigation on oven dry weight basis, %

Q_i = moisture content of the ith layer of soil before irrigation on oven dry weight basis, %

As_i = apparent specific gravity of the ith layer of soil

D_i = depth of ith layer and, n = number of layers in the root zone

3.2.2.3.3 Determination of storage efficiency

The water storage efficiency refers how completely the water needed prior to irrigation has been stored in the root zone during irrigation.

Based on the FC, PWP, BD 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 at the 75% moisture depletion level (Allen et al, 1998).

After determining the storage and the required depths, the storage efficiency was calculated using equation [2.2].

3.2.2.3.4 Determination of distribution efficiency

Furrow irrigation is adaptable where soils and topography are reasonably uniform (Jensen, 1983) and furrows are sloping channels cut into the soil surface and into which a relatively large initial non-erosive stream of water is turned.

The logic behind the evaluation of water distribution uniformity along the furrow is that when irrigation water is applied into a longer furrow with a given discharge, the upper and the lower ends cannot get equal amount of water (Michael, 1997). The length of furrow which can be efficiently irrigated may be as short as 45 m on soils which take up water rapidly, or as much as 300 m or longer on soils with low infiltration rates. For such long furrows the maximum allowable slope is 1% and the furrow stream varies from 0.5 to 2.5 liter per second.

To determine the distribution uniformity of irrigation water in these furrows layouts auguring were done at selected points, starting from the initial to the end of the furrows at regular interval. And at each selected points of the furrow soil samples were collected at different depths with an interval of 30 cm up to 90 cm. And the soil moisture contents of the soils at the selected points were analyzed to determine the depth of water penetration. For calculating the distribution uniformity the root depth of the crop was taken as the zone of distribution and equation [2.4] was used.

4 RESULTS AND DISCUSSION

Batu Degaga Irrigation Project

At Batu Degaga there are 3 electric pumps having an average discharge of 85 liter per second each. Out of the three pumps, only the two pumps are working at a time. The third one is reserved and will substitute the others whenever it is necessary. This does not mean that the discharge of the two pumps is enough to irrigate the whole area. Rather the electric power is not in a position to run the three pumps at the same time. The pumps are working for ten hours per day.

Originally the project was designed and constructed by the World Vision and the structures, even if poorly maintained, still exist. The secondary canals are unlined earthen canals. There are a number of division boxes along the primary canals that are used to divert the water into the secondary canals.

All farmers are using short furrows having an average length of 8 meters with 0.6 meter furrow spacing. Spade is the equipment to open and close furrows while they are irrigating their crops.

During the reallocation of the farm fields to the members, each farmer on average has got 0.5 hectares of land. The main crops grown in the irrigation project area are onion, tomato, maize, and pepper. Among the mentioned crops, onion was the dominant crop produced covering around 50-60% of the irrigable land during the study.

These crops are grown during both rain and dry seasons. During the rainy season, even if the rain is sufficient for the crop, irrigation water is supplemented when vegetable crops are transplanted. The farmers themselves, including their family, do all the farming practices. However, during peak times like harvesting, farmers are forced to hire additional labor in daily wage basis.

In the irrigation project there is no any rule or restriction on the farmers what type of crop to produce. The farmers have the right to choose what type of crop to plant as far as the crop is profitable and the water allocation is adequate to produce the selected crop.

Farmers sell their produce by themselves based on the market price. Recently the representative DA or management records the amount of the yield and incomes so as to collect money from the farmers accordingly. The association charges each member, 120 birr per season per 2500 m^2 area and 40 birr per season for the electric power consumption and for pump and canal maintenance respectively regardless of the type the crop they produced. The individual farmer covers the production costs like fertilizer, chemicals and labor by himself without the involvement of the association.

Here the main production constraint experienced by the farmers is frequent malfunctioning of water pumps. Besides the insufficient discharge of the pumps and high electric consumption, pumps frequently fail. Consequently, farmers are forced to limit area of land under irrigation. Large portion of the irrigation project that are located at the tail end of the main canal are left unproductive for longer time, while the land near the pump station are favored for the water.

Doni Irrigation Project

The discharge in the canal is controlled by manually operated gate. The discharge of the main canal varies from time to time, along with the parent source, Awash River that is also being controlled at Koka dam. The discharge lies in the range of 140 and 300 liters per second with an average discharge of 200 liters per second. The maximum discharge capacity of the main canal of the Doni irrigation project is 368 liter per second.

Water distribution system: A representative farmer assigned by the association through out the year manipulates the gate at diversion weir. Once it is opened, it stays till the rain season comes with regular two over-night interruptions for canal cleanings. The representative DA makes water allocation between Doni and Sifa PA and it is basically governed by the discharge of the Awash River. The distribution can be allocated day and night rotation or for specific period (days interval) within a week. As far as the schedule of irrigation water allocation is for the PA he belongs, farmers have the right to apply the water as much as he wants. That means there is no any restriction how much water a farmer can divert for his field regardless of the size of his farm, especially for head end users. From field observation and results of the questionnaire, due to unwise use of water by the head end users and siltation problems of the main canal the tail end user faced water shortages frequently.

Command area: According to the design document land suitable for irrigation in the area is estimated to be over 500 ha. Taking into consideration the beneficiary capacity, labor availability and input requirement, a gravity system that can irrigate a gross area of 250 ha in two peasant associations was designed. About 100 ha of the land are located in Doni Kombe peasant association and 150 ha in Sefa Denke peasant association. Although the original design is for 250 ha, only 195 ha of land are actually developed. Currently the total actively irrigable area covered by the main canal is 122 ha: i.e., 82 ha for Doni (out of this 30 ha is covered by perennial crops) and 40 ha for Sifa Denke. The main reason for this shortfall is that the canal capacity constructed cannot carry the discharge for the whole area. So farmers, especially at Sifa Denke, are forced to reduce their area considerably.

Crop production: The dominant crops of the area grown under irrigation are onion, tomato maize, and pepper. Most of the produces are sold to wholesalers coming from Addis Abeba. Due to the existence of state owned irrigation farm located adjacent to the project and working there as daily laborers, the farmers have a relatively good exposure to irrigation practice. The types of crops to be grown are selected based on the market condition, the resistance of the crop for disease, water availability and ease of management.

Finance (Fee collection): The committee of the association has the right to collect money from the members. Each farmer is charged 2 birr per 100 kg of any type of crop he produced and there are also additional incomes collected. Such as member ship fee, registration fee, penalty charge and so on. The committee of the association has responsibilities to control farmer to irrigate according to the schedule and charge them if violate the program. They are also responsible to follow and maintain canal structures whenever there is any damage.

The finance of the association is audited and controlled frequently by people representative assigned by the Woreda Finance Bureau.

Production constraints: Farmers prefer to grow some of the selected crops to minimize risks like market failure, disease infestation, high costs of pesticides and insecticides, unavailability of good quality seeds with reasonable prices and so on. These production constraints favored the most dominant crop grown in area to remain onion throughout the seasons and farmers are resistant to change these crops by high value crops. Besides, farmers don't have knowledge about the type and recommended rate of chemicals applied so they are forced to rely on their local knowledge.

4.1 Comparative Performance Indicators

The type and capacity of the irrigation systems of the two irrigation projects selected for the study are shown in Table 4.1.

Table 4.1. Features and computed values of some parameters of the two Irrigation Projects

Irrigation project	*Irrigation system*	*Design Capacity lit/sec*	*Maximum Canal capacity, lit/sec*	*Average discharge, l/s*	*Developed area, ha*	*Actual irrigable area, ha*
Doni	Diversion	368	400	200	195	122
Batu	Pump*	280	300	170**	140	60

*: There are three pumps operating at the irrigation project.
**: Is sum of the discharges of the two currently operating pumps.

The investment costs of the two irrigation projects as obtained from the design documents of the projects are calculated and presented as shown in Table 4.2.

Table 4.2 Investment costs of the two selected Irrigation Projects

Site name	Area developed, ha	Actual irrigable area, ha	Year completed	Service year	Distribution structures cost ('000)	Cost per hectare, birr/ha	Average interest rate %	Construction cost for the present year (PNW)
Batu D.	140	60	1992	20	669.19	11,153.2	10.5*	36, 961.26
Doni K.	195	122	1997	20	1,104.90	9,056.6	10.5*	18,217.93

The Present Net Wroth of the distribution structures is computed using the formula: $Present\ \ Net\ Worth(PNW) = (Initial\ \ \cos t / ha) \times (1 + r)^n$

Where: *r* is interest rate, which is taken from the design document of Doni Irrigation Project and *n* is years from construction time.

The total yields and land coverage of main crops of the two irrigation projects for the cropping calendar of 2003 and 2003/2004 are determined as tabulated in Table 4.3 and 4.4 and used in the comparison of the two projects.

Table 4.3 Total yield and land coverage of Batu Degaga and Doni irrigation projects for the year 2003

Crop	Batu Degaga				Doni		
	Area (ha)	Yield (qt)	Ave. Price, birr/kg	Total Income (birr)	Area (ha)	Yield (qt)	Total Income (birr)
Onion	19.69	1,097.73	1.58	173,441.34	72.00	3,768.44	595,413.52
Tomato	2.38	32.00	0.73	2336.00	18.50	254.33	17,803.10
Maize	52.25	2,292.00	0.90	206,280.00	47.00	2,007.70	180,693.00
Pepper	2.45	4.25	0.50	212.50	4.75	11.00	5,500.00
Popcorn	1.94	16.00	2.50	4,000.00	-	-	-
Bean	6.50	94.00	1.20	11,280.00	12.00	171.50	20,580.00
Perennial	-	-	-	-	30.00	-	106,000
Total	**79.08**			**397,549.84**	**184.50**		**925,989.62**

Table 4.4. Total yields and land coverage of Batu Degaga and Doni irrigation projects for the 2003/2004 cropping season (Oct-Feb.)

Crop	*Batu Degaga*				*Doni*		
	Area (ha)	*Yield (qt)*	*Ave. Price, birr/kg*	*Total Income (birr)*	*Area (ha)*	*Yield (qt)*	*Total Income (birr)*
Tomato	3.3	228.97	1.15	26,331.55	13.00	740.00	85,100.00
Onion	30.6	4,751.73	1.51	717,511.23	65.25	6,874.80	1,038,094.80
Pepper	1.8	35.00	0.50	1,750.00	2.75	53.50	2,675.00
Popcorn	8.0	66.00	2.50	16,500.00	-	-	-
Maize	15.1	663.46	0.90	59,711.40	8.25	509.75	45,877.50
Perennial*	-	-	-	-	30.00	-	35,333.33
Total	**58.8**			**821,804.18**	**119.25**		**1,207,080.63**

*: Is the sum of mango, sugarcane and orange

4.1.1 Evaluation of the individual irrigation projects

The four indicators *RWS, RIS, WDC & GRI were* used as parameters to evaluate and characterize the performance of individual irrigation projects separately and used to see the variation of the indicators spatially.

To calculate the CWR and IR of the two irrigation projects, crop area coverage and the planting dates of each crop are presented as Table 4.5 & Table 4.6 for the 2003/2004 cropping season.

Table 4.5. Area coverage of dominant crop at Batu Degaga

Crop type	*Area coverage, ha*	*Percent of the total area, %*	*Planting date*	*Irrigation interval, days*
Onion	30.63	52	Oct 28	8
Tomato	3.25	6	Oct 23	5
Maize	23.13*	39	Nov 6	9
Pepper	1.75	3	Nov 3	5
Total	58.75	100		

*: Is the sum of popcorn and maize.

Table 4.6. Area coverage of dominant crop at Doni

Crop type	*Area coverage, ha*	*Percent of the total area, %*	*Planting date*	*Irrigation interval, days*
Onion	65.25	55	Oct 12	5
Tomato	13.00	11	Oct 29	4
Maize	8.25	7	Oct 3	6
Pepper	2.50	2	Oct 10	5
Sugarcane	6.00	5	Jan 1	8
Mango	5.00	4	Jan 1	8
Orange	19.00	16	Jan 1	8
Total	119.00	100		

The net crop water requirement (CWR) and the net irrigation requirement (IR) were computed for each irrigated crop for the 2003/2004 cropping season (Oct-Feb). The crop coefficients provided with CropWat Computer program were used (input: planting dates and growth length in days) to calculate the crop water requirement at each growth stage. For Batu Degaga and Doni the result of the computer program is presented as shown in Table 4.7 and Table 4.8, respectively:

Table 4.7 Results of CWR and IR of Batu Degaga irrigation project

Crop	*Area, ha*	*Total rainfall, mm/season*	*Effective rainfall, mm/season*	*Crop water requirement: Season (mm/season)*	*Irrigation requirement mm/season*
Onion	30.63	57.82	53.75	480.08	426.33
Tomato	3.25	148.27	128.30	777.26	648.96
Maize	23.13	164.37	141.33	657.96	516.63
Pepper	1.75	132.93	115.93	657.26	541.33
Total	58.75				

Table 4.8 Results of CWR and IR of Doni irrigation project

Crop	*Area, ha*	*Total rainfall, mm/season*	*Effective rainfall, mm/season*	*Crop water requirement: Season (mm/season)*	*Irrigation requirement mm/season*
Onion	65.25	48.04	45.53	393.67	348.14
Tomato	13.00	138.77	130.36	642.19	511.83
Maize	8.25	83.63	79.19	508.05	428.86
Pepper	2.50	77.01	72.99	518.40	445.42
Sugarcane	6.00	679.93	527.62	2034.19	1506.56
Mango	5.00	679.93	527.62	1916.03	1388.40
Orange	19.00	679.93	527.62	1298.78	799.00
Total	119.00				

The total crop water demand for the 2003/2004 cropping season of Batu irrigation project was calculated as:

$$CWR_{onion} \times (area_{onion} / area_{total}) + CWR_{tomato} \times (area_{tomato} / area_{total}) + etc \quad =$$

Where: *CWR_{crop}* is the water requirement of a crop calculated and taken from Table 4.7, *$area_{crop}$* is irrigated areas of the respective crops taken from the same Table and *$area_{total}$* is the total irrigated area (58.75 ha).

The result is 571.82 mm/season. To change the depth to volume of CWR multiply it by the total irrigated area, i.e. $58.75 \times 10^4 \times 571.82 \times 10^{-3}$ m^3 = 335,944.25 m^3 /season. The total irrigation requirement is calculated in the same way and the result is 477.61 mm/season i.e. 280,598.80 m^3 / season.

The amount of water or depth of water diverted during the whole season for Batu Degaga was calculated as: volume of water diverted divided by total irrigated area. The result is (722,160.00 / 58.75) = 1,229.20 mm

From Appendix D-1, the total rainfall for the cropping season (Oct- Feb) at Batu was 94.80 mm and CWR was 571.82 mm.

Table 4.9 Results of some parameters for cropping season 2003/2004

Site	*Command area, ha*	*Production 2003/2004, birr*	*Irrigation supply,*		*CWR, mm*	*IR, mm*	*Peak IR, l/sec/ha & lit/sec*	*Canal capacity, l/sec*	*Total RF, mm*
			M^3	mm					
Batu	58.75	397,549.84	722,160	1,229.20	571.82	477.61	1.56= 219.96	170.00	94.80
Doni	119.00	925,989.62	1,797,120	1510.18	722.56	547.76	0.92= 109.48	200.00	106.70

Relative Water Supply = (Irrigation diverted + Total rainfall) / (CWR)

= (1,229.20 + 94.80) / (571.82) = 2.32

Relative Irrigation Supply = Irrigation diverted / Irrigation requirements

= 1,229.20 / 477.61 = 2.57

The projects' irrigation requirements were calculated (Table 4.8) with CropWat using climatic data, planting pattern, planting dates and the area coverage of individual crop for the cropping season of 2003/2004 (Oct-Feb). And the results were:

Table 4.10 Peak IR of Batu Degaga and Doni irrigation projects

		Sep	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*
Irrigation req., lit/sec/ha	Batu	0.05	0.68	0.79	1.13	1.56	0.74	0.22
	Doni	0.54	0.92	0.85	0.82	0.58	0.31	0.26

The peak irrigation requirements of Batu irrigation as a whole for 2003/2004 cropping season occurred in January the value that was, 1.56 lit/sec/ha. This is for continuous flow, and for 10 hours pump running time in a day then the peak consumptive demand will be:

1.56 × cropped area for that month × 24/10 = 1.56 × 58.75 × 2.40 = 219.96 lit/sec

The peak irrigation requirement (219.96 lit/sec) was determined for the irrigated area of 58.75 ha when the crops covering the area were taken from Table 4.5, for their respective area coverage ratio.

The actual discharge capacity of the main canal at the system head was 170 lit/sec, which was the total discharge of the two pumps. This value was taken because for the Batu irrigation project the limiting factor to satisfy the water demand of the crops was the discharge of the pumps rather than the canal capacity. For the irrigation system of diversion weir like that of Doni, however, the canal capacity is the limiting factor.

Water Delivery Capacity = Actual canal capacity / Peak demand

= 170 /219.96 = 0.77

The gross investment cost per hectare of each irrigation projects were calculated for the actual irrigable areas of the projects rather than the developed irrigable area. Because even though the total irrigation areas developed were 140 ha and 195 ha, the actual irrigable areas were by far less than these values i.e. only 60 ha for Batu and 122 ha for Doni. If the developed areas were considered for the investment and the total production calculated were from the actual irrigable land the conclusion would be erroneous and lead to unrealistic decision.

The base years taken to calculate the Present Net Worth was the year 2004 and the age of the irrigation projects were 12 and 7 years for Batu and Doni, respectively. The average interest rate used in the calculation was taken from the design documents of the irrigation projects.

The GRI of Batu for the year 2003 was calculated as shown in Table 4.2 was:

Gross return on investment = Gross production (Table 4.13) / Costs of investment (Table 4.2) = 5,027.25 / 36,961.24 = 13.6%

The construction costs were collected from the terminal and rehabilitation report of Doni and Batu irrigation projects, respectively. The investment cost of the diversion weir at Doni was not included in the analysis. Because as stated by Molden et al (1998) the intention or the desire is to compare the water delivery structures and the diversion weir may serve other non-irritation purposes.

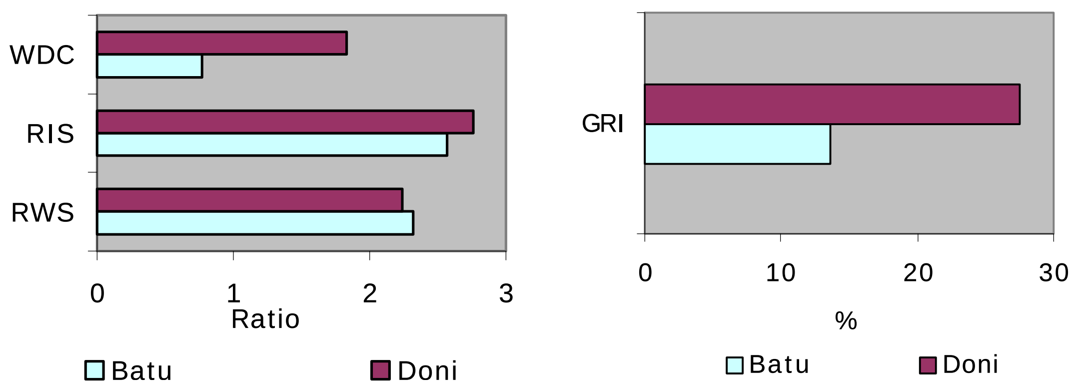
With the same procedures the values of the parameters for Doni were determined and summarized below.

Table 4.11. Summary of results for RWS, RIS, WDC and GRI

Site	*RWS, ratio*	*RIS, ratio*	*WDC, ratio*	*GRI*, %*
Batu Degaga	2.32	2.57	0.77	13.60
Doni	2.24	2.76	1.83	27.55

*GRI was calculated based on the 2003 productions.

Fig 4.1. Spatial variations of some of the indicators



When we see the results of the water supply indicators (RWS, RIS, and WDC) of each irrigation project from Table 4.11, the values of RWS and RIS are higher than 2. These higher and nearly equal values of RWS and RIS indicated that there was a generous supply of water and the sole water provider was irrigation, no contribution of rainfall. It is better to have RIS close to 1 than a higher or lower value (Molden et al, 1998).

The value of WDC at Batu Degaga is less than 1, so the capacity of the pumps at peak time of crop demand is below the requirements. The capacity of the pumps is in constraint to meet the maximum crop water requirement. The WDC of Doni irrigation project is higher than 1, so the canal capacity is not a constraint to meet crop water demands. Values close to 1 indicate that there may be difficulties meeting short-term peak demands (Molden et al, 1998).

GRI of the projects are 13.6% and 27.55% for Batu Degaga and Doni, respectively. These values indicate that Doni has higher rate of return on investment than Batu Degaga. The possible reason for lower GRI value of Batu is that large irrigable area is reduced from the project due to low pump capacity. The water distribution structures of the project are designed and constructed for 140 ha land but the actual irrigable area is only 60 ha.

4.1.2 Comparison of the two irrigation projects

To compare the two selected irrigation projects in terms of their output per area and water supply, four comparative indicators (*output per cropped area; output per unit command; output per unit irrigation supply and output per unit water consumed*) were used.

As seen in Table 4.4, the crop production for the year 2003 of Batu Degaga was about 3,535 quintal. The cropped area was 79 ha with gross income of 397,548.84 birr. The cropped area was greater than the command area because some areas were irrigated more than once in the same year.

For the 2003/2004 cropping season the total production of Batu irrigation project was 5,745.16 qt. This was planted on 58.75 ha, net command areas generating gross income of 821,804.18 birr. The prices of the crops were fluctuating time to time, so in order to avoid over or under estimation average values were considered. Such measure is recommended in Molden et al (1998).

The total volume of water diverted to the Batu irrigation project for 58.75 ha of land during the season (Oct 20-Feb 15, with average discharge of 170 liter per second and 10 hrs/day flow) was 722,160 m^3.

The total volume of water diverted to the Doni irrigation project during the season (Oct 1-Feb 1, with average discharge of 200 lit / sec and continuous flows) was 1,797,120 m^3.

Table 4.12. Cropped areas, irrigation water and yield of Batu and Doni irrigation projects.

Site	Cropped area, ha	Command area, ha	Water consumed, m^3/season	Irrigation supplied, m^3/season	Production, birr	
					For year 2003	For 2003/2004 cropping season
Batu	79.08	60	335,944.25	722,160.00	397,549.84	821,804.18
Doni	184.50	122	859,846.40	1,797,120.00	925,989.62	1,207,080.83

The four comparative indicators were determined for the Batu Degaga as follow (from Table 4.12):

Output per cropped area for the year 2003 = 397,549.84 / 79.08

= 5,027.25 birr/ha

Output per unit command area for the year 2003 = 397,549.84 / 60

= 6,625.83 birr/ha

Output per unit irrigation supply for cropping season of 2003/2004 =

= 821,804.18 /722,160 = 1.14 birr/m^3

Output per unit water consumed for cropping season of 2003/2004 =

= 821,804.18 / 335,944.25 = 2.45 birr/m^3

With the same procedures, the values of the parameters for Doni were determined and tabulated as seen in Table 4.13

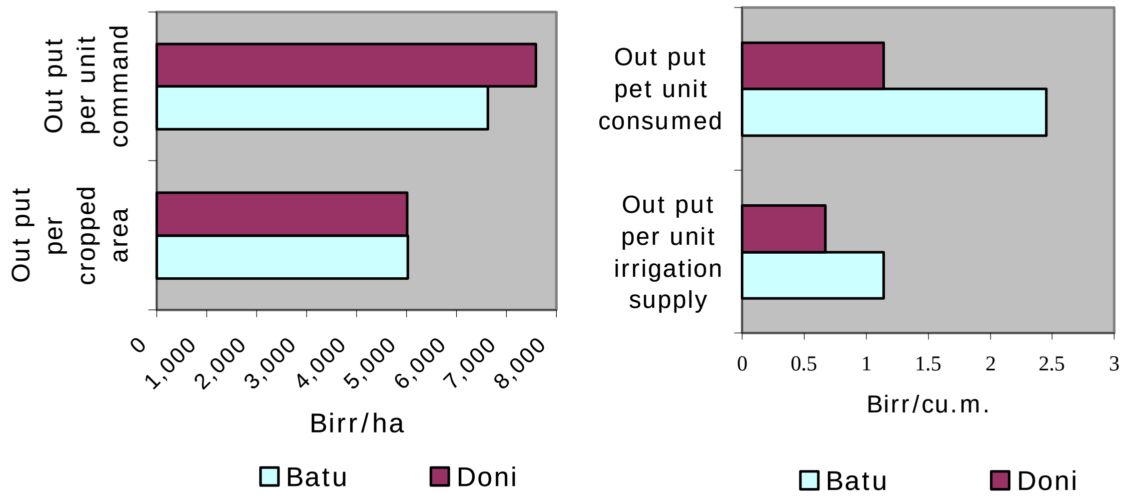
Table 4.13 Summary of calculated parameters for Batu Degaga and Doni

Site	*Output per cropped area, birr/ha*	*Output per unit command, birr/ha*	*Output per unit irrigation supply*, birr/m^3*	*Output per unit water consumed*, birr/m^3*
Batu	5,027.25	6,625.83	1.14	2.45
Doni	5,018.90	7,590.00	0.67	1.14

*These values were computed for the cropping season 2003/2004

From Table 4.13 out put per cropped area of the two projects were more or less equal but the value of the output per command area of Doni was greater than the value of Batu Degaga. This was attributed to the cropping intensities and the type of crop grown in each area. The cropping intensity of Batu Degaga (132%) was lower than Doni (151%) while the large portion of the irrigable area was covered with high value cash crop (onion) at Doni (39%) than Batu Degaga (25%).

Fig 4.2 Variation of production per area and water supply



Again from Table 4.13 regarding the output in relation to water supply for the cropping season of 2003/2004 Batu Degaga has higher values than Doni. This indicated that each volume of water produced much yields at Batu than Doni and large amount of water was diverted at Doni than Batu Degaga.

The output per unit irrigation supply for Batu Degaga was 1.14 while Doni was 0.67. This indicates that irrigation water was more abundant at Doni than Batu Degaga and water was used to produce more at Batu Degaga.

When land is limiting relative to water, output per unit land may be more important. Where water is a limiting factor to production, output per unit water may be more important (Molden et al, 1998). This scenario was observed in the two irrigation projects. At Batu Degaga water was limiting factor so the value of water has to be given emphasis and the reverse was true for Doni.

If we want to compare these irrigation projects with similar irrigation projects of other countries, the production has to be changed to the Standardized Gross Value Products (SGVP) using the world market prices of the production year and the equation developed by IWMI (Appendix A).

4.1.3 Trend performance of each irrigation scheme

Trend performance can be computed for most of the comparative indicators and the performance of the irrigation projects through time can be evaluated. Here due to non-availability of secondary data on total yield of each year, only the trend of FSS of the two irrigation projects was computed.

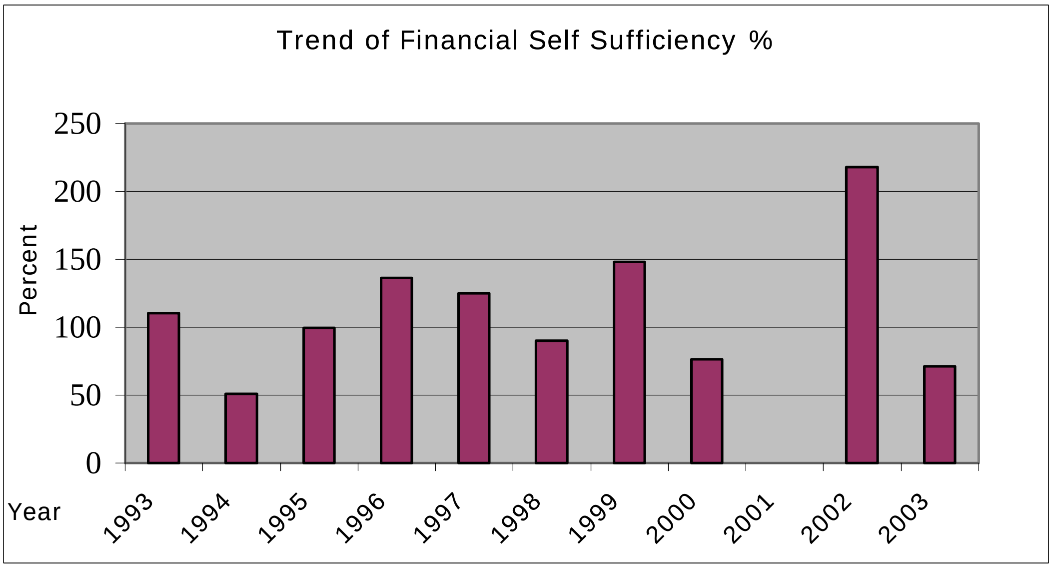
For Batu Degaga

Table 4.14. Batu Degaga Trend of FSS

Year	*Total Revenue, birr*	*Total O & M, birr*	*Financial self sufficiency %*
1993	4,458.00	4,041.00	110.32
1994	8,808.00	17,283.83	50.96
1995	14,765.00	14,861.26	99.35
1996	27,638.30	20,297.29	136.17
1997	38,681.55	30,934.40	125.04
1998	33,532.20	37,144.09	90.28
1999	35,962.00	24,305.91	147.96
2000	33,020.05	43,203.53	76.43
2001*	0.00*	0.00	0.00
2002	30,727.00	14,106.00	217.83
2003	28,721.00	40,413.47	71.07

* No irrigation

Fig 4.3 Trend performance of FSS of Batu Degaga



Batu Degaga irrigation project was established 1993 and even though not consistent it had relatively good organized Water Use Association (WUA) than Doni.

In calendar year 2001, there was no irrigation practice due to difficulty to cover the expense of electric consumption. In 2002 there was transferred money that should be collected in the previous year; in 2003 money collection was not completed (delay of money collection).

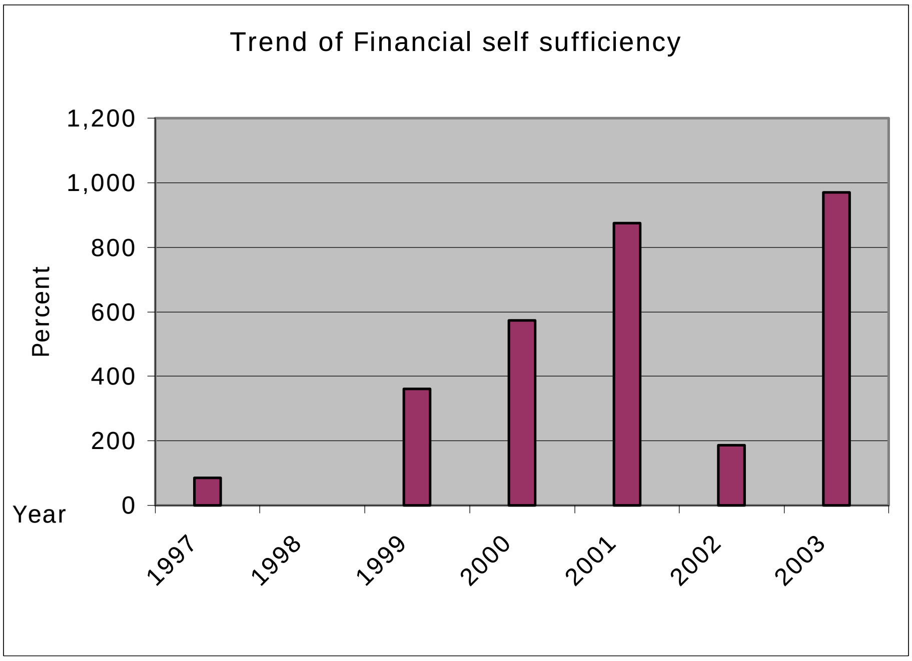
From the Table 4.14 above large amount of money has been spent by the association for O & M at Batu Degaga. These expenses were attributed or spent to cover electric consumption and maintenance of the pumps. Though not consistent, some increment was observed. The inconsistency was mainly due to pump failure, electric cost coverage problems and yield fluctuations from year to year.

For Doni

Table 4.15 Doni Trend of FSS

Year	*Total Revenue, birr*	*Total O & M, birr*	*Financial self sufficiency %*
1997	1,693	1,986	85.25
1998	0.00	0.00	0.00
1999	2,288	634	360.88
2000	13,866	2,417.2	573.64
2001	12,189	1,394.5	874.08
2002	12,151	6,523.9	186.25
2003	25,952	2,674.1	970.49

Fig 4.4 Trend performance of FSS Doni



In 1997 only membership fee was collected and 1998 the association was not functional and it was on the process of organizing and establishing the irrigation association.

From 1999 onwards, there was an additional income (besides other fees made by the member for the association) from productions made by the farmers. Every farmer has paid 2 birr per 100 kg of his product regardless of the type of crop he produced and this rule was applied at the production year 2000.

From Table 4.15, there was no as such high O & M cost at Doni; it was attributed to the diversion weir. That is once the structure was built, its operational cost would be very low and farmers would have the chance to strengthen them selves for future expenditures and enlarge their command area. Income has increased with high rate than O & M. The reason that after each production seasons the association has collected additional income while little money has been spent for operation and maintenance. The other reason for low maintenance cost spent by the association was that the members have cleared the main canals by them selves and the labor cost was not included in the analysis.

Despite some fluctuation at Doni, FSS has increasing trend and the association has the potential to cover huge investments and can accommodate maintenance costs that had never been done by the association. This increasing trend clearly showed that farmers were producing more from time to time.

Total income collected from the farmers at Batu Degaga was much higher than Doni & total running cost was also higher at Batu Degaga but fluctuating.

Additionally the incomes collected from the farmers in the irrigation projects have different nature. At Doni farmers have been charged for the income of their crop productions (this was the larger portion among other) timely so no delay of payment could occur unlike Batu Degaga. At Batu Degaga there were no income charges imposed or made by the farmer, rather seasonal payment has been made according to the farm size so there would be a chance of transfer or delay of payments. So inconsistency might occur at Batu Degaga.

4.2 Farmer's fields evaluation at each irrigation projects for their efficiencies

Batu Degaga Irrigation Project

In this irrigation project water has been diverted from the river using three electric pumps and discharged into the main canal through small reservoir, which was used to dissipate the energy. Farmers have the right to irrigate their fields at any time and the amount they feel the crop needs.

Three farmers' fields were selected to compare their irrigation water use efficiencies in the Batu Degaga irrigation project. The areas of the selected fields were 0.5 ha. The slopes of the fields that follow the general topography of the irrigation projects were less than one percent. The textures of the soils were classified as silt loam. The soils are generally described as medium textured having an average bulk density of 1 g/cm^3. The pH of the soils ranges from 6.9 to 7.4 with sufficient organic matter.

All the selected fields were covered with a single crop, that was, onion. The average lengths of furrows were six meters with average furrow spacing of 0.6 meters.

Table 4.16 Physical soil properties of selected fields of Batu Degaga irrigation project

Farmer's Field	*Soil depth, cm*	*pH*	*Bulk Density gm/cm³*	*EC_e, dSm*	*FC %*	*PWP %*	*Soil texture class*
Field 1	0-30	7.31	1.03	0.69	27.48	19.45	Silt loam
	30-60	7.35	0.95	0.71	23.46	17.23	Silt loam
	60-90	7.30	1.01	0.71	24.33	19.62	Silt loam
Field 2	0-30	6.88	1.02	0.39	26.14	18.66	Silt loam
	30-60	7.09	0.96	0.46	23.98	17.40	Silt loam
	60-90	7.16	1.02	0.52	24.66	19.89	Silt loam
Field 3	0-30	7.20	1.21	0.80	34.46	23.38	Silt loam
	30-60	7.31	1.05	0.83	29.96	20.74	Silt loam
	60-90	7.36	1.04	0.82	26.94	20.34	Silt loam

Table 4.17. Applied irrigation water measurement (flume average) at Batu Degaga

Farmer's Field	*Time elapsed (sec)*	*Flume height (cm)*	*Respective discharge (lit/sec)*	*Areas of fields (m^2)*	*Total volume (lit)*	*Depth applied (mm)*
Field 1	14,910.00	15.00	9.40	2,520.0	140,154.0	55.62
Field 2	11,250.00	14.50	8.95	1,652.0	99,180.0	60.04
Field 3	8,092.25	14.75	9.18	1,224.3	74,287.4	60.68

Table 4.18. Average soil moisture contents before and two days after irrigation at Batu

Farmer's Field	*Time of soil sampling*	*Soil moisture contents, % volume*		
		Soil depths, cm		
		0-30	30-60	60-90
Field 1	Before irrigation	28.34	28.02	31.82
	After irrigation	35.18	32.07	33.80
Field 2	Before irrigation	23.05	23.55	26.38
	After irrigation	29.29	27.43	29.56
Field 3	Before irrigation	24.93	26.54	30.15
	After irrigation	33.47	30.88	31.27

Table 4.19. Calculated efficiencies of selected fields at Batu Degaga irrigation project

Farmer's Field	*Efficiencies, %*		
	Application	Storage	Distribution
Field 1	59.00	100.00	100
Field 2	50.60	95.96	100
Field 3	64.29	84.58	100

Here in Batu irrigation project every liter of water has cost that is manifested through electric bill used to pump the irrigation water. 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. The distance of the field from the water source did not limit the farmers from applying excess water. This phenomenon was more demonstrated by the average depths of water applied (Table 4.17) by the farmers in relation to their locations.

Field 1 was located at the head of the main canal while Field 2 was located at the middle of the main canal. Looking into depths of water applied (Table 4.17), more water was applied by Field 2 than Field 1. As regards of application efficiencies, from Table 4.19, Field 1 was most efficient. However, these three irrigated fields can be considered as 'in the order of similar condition' for their irrigation water management efficiencies.

The water requirements of major crops grown in the irrigation projects were determined using CropWat computer model based on the irrigation intervals of each crops practiced by the farmers at each plots (Table 4.20). The calculation was made taking the irrigation efficiency of small-scale irrigation as 45%, which has been proved to be the reality of small-scale irrigation schemes (Chancellor and Hide, 1997). These figures can be used as a bench mark when further studies are proposed.

Table 4.20. Crop Water Requirements of onion for fixed irrigation interval at Batu Degaga

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS l/s/ha
28/10	40.91	100.00	0.70	28.64	0.00	0.00	28.64	0.92
5/11	41.47	100.00	0.70	29.03	0.00	0.00	29.03	0.93
13/11	42.04	100.00	0.71	30.04	0.00	0.00	30.04	0.97
21/11	42.58	100.00	0.80	34.03	1.23	1.14	32.90	1.06
29/11	43.10	100.00	0.89	38.47	8.83	8.06	30.41	0.98
7/12	43.56	100.00	0.99	42.95	12.99	11.87	31.08	1.00
15/12	43.97	100.00	1.05	46.10	13.39	12.28	33.82	1.09
23/12	44.29	100.00	1.05	46.50	11.47	10.59	35.91	1.15
31/12	44.77	100.00	1.05	47.01	6.09	5.99	41.02	1.32
8/1	46.00	100.00	1.05	48.30	2.39	2.39	45.91	1.48
16/1	47.18	100.00	1.02	48.11	0.64	0.64	47.48	1.53
24/1	42.15	100.00	0.97	40.89	0.80	0.80	40.09	1.47
Total	522.02			480.08	57.82	53.75	426.33	1.15

The irrigation scheduling was calculated taking the farmers practices into consideration. This helps to create similar conditions with the farmers' irrigation practices and facilitates to examine and compare the efficiencies of the selected fields against the optimum. Scheduling at farmers fields should consider fixed interval and fixed water depths application techniques through the growing stages because farmers are not in a position to measure and monitor the soil moisture contents of the soil prior to irrigation to use scheduling. Of course, these alternatives must be seriously studied and supported by location specific research recommendations.

Table 4.21 Irrigation Scheduling of onion at Batu Degaga

Crop Data: Small Vegetable Planting date: 28/10
- Application Timing: irrigate each 8days.
- Applications Depths: Fixed depths of 40mm each.
- Start of Scheduling: 28/10

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
28/10	25.0	7.5	0.0	0.0	1.3	35.7%	20.0	0	40.0	20.0
5/11	30.6	9.9	0.0	0.0	1.7	78.5%	22.5	8	40.0	17.5
13/11	36.2	12.6	0.0	0.0	2.1	85.4%	24.8	8	40.0	15.2
21/11	41.8	15.5	0.0	0.0	2.6	90.0%	27.4	8	40.0	12.6
25/11	44.6	17.1	1.9	1.9	4.3	100.0%	14.8			
29/11	47.4	18.8	0.0	0.0	3.2	87.0%	30.3	8	40.0	9.7
30/11	48.1	19.2	5.3	0.0	4.6	100.0%	4.6			
5/12	51.6	21.4	7.4	7.4	5.0	100.0%	21.5			
7/12	53.0	22.3	0.0	0.0	4.4	93.1%	30.9	8	40.0	9.1
10/12	55.1	23.6	8.4	8.4	5.3	100.0%	7.4			
15/12	58.6	26.0	8.5	8.5	5.7	100.0%	26.6	8	40.0	13.4
20/12	60.0	27.0	8.0	8.0	5.8	100.0%	20.8			
23/12	60.0	27.0	0.0	0.0	4.8	94.5%	37.3	8	40.0	2.7
25/12	60.0	27.0	7.1	5.8	5.8	100.0%	5.8			
30/12	60.0	27.0	2.5	2.5	5.8	100.0%	32.4			
31/12	60.0	27.0	0.0	0.0	4.9	83.7%	37.3	8	40.0	2.7
1/1	60.0	27.0	3.8	0.0	5.8	100.0%	5.8			
6/1	60.0	27.0	2.3	2.3	5.9	100.0%	32.9			
8/1	60.0	27.0	0.0	0.0	4.0	74.6%	41.8	8	40.0	0.0
11/1	60.0	27.0	1.2	1.2	6.0	100.0%	18.7			
16/1	60.0	27.2	0.5	0.5	3.7	84.2%	43.8	8	40.0	0.0
21/1	60.0	28.2	0.3	0.3	6.0	100.0%	33.6			
24/1	60.0	28.8	0.0	0.0	3.3	69.1%	45.9	8	40.0	0.0
26/1	60.0	29.2	0.7	0.7	5.9	100.0%	17.0			
Total			57.8	47.4	445.2	92.7%			480.0	102.8

From Table 4.20, which was calculated with CropWat, the maximum irrigation requirements of the crop with 8 days interval was only 47.5 mm depth of water. This value can be used for the whole farmers' fields for their similar characteristics required to determine the crop water requirements of the area. But the averaged actual water applied by the farmers with 8 days interval ranged from 55 to 61 mm (Table 4.17) that was more than the calculated value. This showed that the farmers were applying more water than the required.

The distribution efficiencies of these farms were 100%. This indicated that, after irrigation, the effective root zones of the crop in the furrow were uniformly saturated. It is not surprising to find such results if we examined the situations existed in the irrigation fields.

The first reason playing the major role to this high distribution efficiency of the fields was furrows layout. The furrows were very short, branched and they were closed after running some zigzagged distances (Fig 4.5). Although no water was allowed to escape from the furrows, the flow rate was so high (Table 4.17) that every portion of the furrow might get water within short time. The water trapped in the furrow was forced to percolate into the soil so all parts of the furrow have the chance to get equal amount of water in each irrigation time.

As explained earlier the soil moisture contents was investigated down the profile to the depth of 90 cm and the moisture contents of the soil down the profile has an increasing trend (Table 4.18). These phenomena lead to the conclusion that water was lost by deep percolation than runoff and evaporations.

Fig 4.5. Short and closed furrows layout at Batu Degaga

Doni Irrigation Project

Three farmers' fields were selected to compare their irrigation water use efficiencies. The average areas of the selected fields were 0.7 ha each. The slopes of the fields follow the general topography of the irrigation projects and lie from 0.5%-3%. The textures of the soils were classified as loam to silt loam. The soils are generally described as medium textured with range of bulk density of 0.91 to 1.25 g/cm^3. The pH of the soils ranges from 6.7 to 7.4 with sufficient organic matter. The effective depth of soils ranges from 30cm to 100cm.

All the selected fields were covered with a single crop onion. The average lengths of furrows were eight meters with average furrow spacing of 0.6 meters.

Except Field III the other two fields have soil depths up to one meter while the earlier one was shallow and has hard soil strata beneath 30 cm.

The farmers were applying irrigation water based on their traditional belief (onion gives more yield if watered more). Farmers were applying water regardless of the water requirements of the crop. The average intervals of applying irrigation water for onion on the three fields were 5-6 days. If the soils still too wet, farmers apply a reduced amount

The maximum furrow length (straight part of the furrow) in the fields of the selected irrigation projects was 8 m and the furrow layouts in irrigation fields were not straight and did not run in the same direction as anticipated. They were curved and/or branched to the opposite inflow direction of the initial furrow stream and had different shapes. Every farmers of the scheme practiced these furrows layout and farmers might choose or construct different layout according to his field slope and direction of slope in order to maximize water application and distribution along the furrow (Fig 4.6).

Table 4.22 Physical soil properties of selected fields of Doni irrigation project

Farmer's Field	*Soil depth, cm*	*pH*	*Bulk Density gm/cm^3*	*EC_e, dSm*	*FC %*	*PWP %*	*Soil texture class*
Field I	0-30	7.13	1.04	0.66	22.53	14.62	Loam
	30-60	7.19	1.12	0.74	23.49	18.37	Loam
	60-90	6.98	1.08	0.63	27.78	17.26	Loam
Field II	0-30	6.92	0.98	0.52	22.77	15.98	Silt loam
	30-60	6.76	0.91	0.43	21.39	17.30	Silt loam
	60-90	6.72	0.96	0.40	23.37	18.42	Silt loam
Field III	0-30	7.38	1.25	0.93	25.51	19.58	Loam

Table 4.23 Applied irrigation water measurement (flume average) at Doni

Farmer's Field	*Time elapsed (sec)*	*Flume height (cm)*	*Respective discharge (lit/sec)*	*Areas of fields (m^2)*	*Total volume (lit)*	*Depth applied (mm)*
Field I	8,151.95	8.67	4.03	720.65	32,852.33	46.97
Field II	4,035.25	11.40	6.24	589.57	25,179.96	42.71
Field III	7,369.00	8.00	3.50	810.23	25,791.50	31.83

Table 4.24 Average soil moisture contents before and two days after irrigation, Doni

Farmer's Field	*Time of soil sampling*	*Soil moisture contents,* % volume		
		Soil depths, cm		
		0-30	30-60	60-90
Field I	Before irrigation	18.43	19.61	20.77
	After irrigation	23.37	23.12	22.90
Field II	Before irrigation	28.11	25.86	27.97
	After irrigation	32.19	30.16	32.09
Field III	Before irrigation	29.24	-	-
	After irrigation	32.58	-	-

Table 4.25 Calculated efficiencies of selected fields at Doni irrigation project

Farmer's Field	*Efficiencies, %*		
	Application	Storage	Distribution
Field I	53.75	80.41	100
Field II	58.87	98.67	100
Field III	31.46	104.70	100

From the Table above, the application efficiencies of the three farmers were in the ranges of 30%-60%, which was considered as inefficient and indicated that the farmers were applying excess water to their fields. The storage efficiencies of these fields can be regarded as high. These however need to be interpreted together with the application efficiency

When the three plots based on their application, Field II was more efficient than Field I. Field III was the least efficient. The comparison made above could be more convincing if the values of their storage efficiencies were considered integrally. Field III that was ranked as the least in application efficiency has a storage efficiency of 104.7%. These phenomena can be explained as follow.

Even though the aim of applying irrigation water to a field is to re-fill the soil with moisture that will be easily available to the crop, care must be taken not to over irrigate. From the field observation of Field III, and from soil samples before and after irrigation, some issues were identified. For instance the soil depth of this field was very shallow. Below 30 cm there was a hard pan and water could not infiltrate deeper. When we see Table 4.23 the average depth of water, which had been applied it was the least among others but it was higher than the optimum depth of water calculated using CropWat for five days irrigation interval.

Another issue observed at the field was that, the farmers were applying the same amount of water as the previous irrigation. This type of practice was common in the three farmers' field but the effect was exaggerated in Field III. Besides the shallowness of the soil, the farmer was applying water more frequently than the selected fields. And it was common to see algae covering considerable portion of the furrows, which is a typical sign of extended water ponding. At the lower end of the field the soil lying above the hard pan was very much saturated which was reflected on the storage efficiency (Table 4.25).

Table 4.26 Crop Water Requirements of onion at Doni

Date	ETo	Planted Area	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS
	(mm/period)	(%)		----------	(mm/period)	---------		l/s/ha
12/10	24.40	100.00	0.70	17.08	0.00	0.00	17.08	0.88
17/10	24.15	100.00	0.70	16.91	0.00	0.00	16.91	0.87
22/10	23.92	100.00	0.70	16.74	0.00	0.00	16.74	0.86
27/10	23.69	100.00	0.70	16.58	0.00	0.00	16.58	0.85
1/11	23.46	100.00	0.74	17.24	0.00	0.00	17.24	0.89
6/11	23.25	100.00	0.79	18.44	0.00	0.00	18.44	0.95
11/11	23.04	100.00	0.85	19.62	0.00	0.00	19.62	1.01
16/11	22.84	100.00	0.91	20.79	0.00	0.00	20.79	1.07
21/11	22.66	100.00	0.97	21.94	0.12	0.12	21.81	1.12
26/11	22.48	100.00	1.03	23.08	1.93	1.84	21.24	1.09
1/12	22.31	100.00	1.05	23.43	3.64	3.43	19.99	1.03
6/12	22.16	100.00	1.05	23.26	4.78	4.51	18.76	0.96
11/12	22.01	100.00	1.05	23.11	5.47	5.15	17.96	0.92
16/12	21.88	100.00	1.05	22.97	5.78	5.46	17.52	0.90
21/12	21.76	100.00	1.05	22.85	5.82	5.50	17.35	0.89
26/12	21.65	100.00	1.05	22.73	5.66	5.36	17.38	0.89
31/12	21.99	100.00	1.03	22.64	5.03	4.79	17.86	0.92
5/1	22.40	100.00	1.00	22.32	4.89	4.67	17.66	0.91
10/1	22.76	100.00	0.96	21.93	4.93	4.71	17.22	0.89
Total	432.80			393.67	48.04	45.53	348.14	0.94

When we examine the moisture contents of the soils of all fields down to the profile, it has an increasing trend. This indicates that more water has percolated below the root zone of the crop after irrigation. This conclusion was supplemented and supported by the figures obtained through the determination of distribution uniformity along the furrows.

From application efficiencies of the three farmers and the depth of water applied by the farmers (Table 4.25 and Table 4.23), we can conclude that water application was excessive i.e. much higher than the crop water requirements (Table 4.26). The application efficiency of the three fields was considered as poor. Among the factors reducing the efficiency, applying large amount of water to the field and subsequent deep percolation was the first. Among the factors reducing the efficiency the occurrence of deep percolation was manifested by the high storage efficiencies of all farmers' fields and high moisture contents of the soil below the root zone of the crop (Table 4.24). Since the furrows were, short, branched and closed (Fig 4.6) runoff at the lower ends might not be the factor reducing the application efficiency. Further more, the soils were saturated and so some portion of water applied might be lost through evapotranspiration.

Fig 4.6 Furrows at Doni have different layout according to the slope of the field

Table 4.27 Irrigation Scheduling of onion at Doni

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- Application Timing: Irrigate each 5days.
- Applications Depths: Fixed depths of 20mm each.
- Start of Scheduling: 12/10

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
12/10	35.0	10.5	0.0	0.0	3.4	100.0%	12.2	0	20.0	7.8
17/10	39.9	12.6	0.0	0.0	3.3	99.2%	16.9	5	20.0	3.1
22/10	44.8	14.8	0.0	0.0	3.4	100.0%	16.9	5	20.0	3.1
27/10	49.7	17.1	0.0	0.0	3.3	100.0%	16.7	5	20.0	3.3
1/11	54.6	19.7	0.0	0.0	3.4	100.0%	16.6	5	20.0	3.4
6/11	59.5	22.3	0.0	0.0	3.6	100.0%	17.5	5	20.0	2.5
11/11	64.4	25.1	0.0	0.0	3.8	100.0%	18.7	5	20.0	1.3
16/11	69.3	28.1	0.0	0.0	4.1	100.0%	19.9	5	20.0	0.1
21/11	74.2	31.2	0.0	0.0	4.3	100.0%	21.0	5	20.0	0.0
25/11	78.1	33.7	1.5	1.5	4.5	100.0%	17.2			
26/11	79.1	34.4	0.0	0.0	4.5	100.0%	21.7	5	20.0	0.0
30/11	83.0	37.1	3.3	3.3	4.7	100.0%	16.9			
1/12	84.0	37.8	0.0	0.0	4.7	100.0%	21.6	5	20.0	0.0
5/12	84.0	37.8	4.6	4.6	4.7	100.0%	15.7			
6/12	84.0	37.8	0.0	0.0	4.7	100.0%	20.4	5	20.0	0.0
10/12	84.0	37.8	5.4	5.4	4.6	100.0%	13.6			
11/12	84.0	37.8	0.0	0.0	4.6	100.0%	18.3	5	20.0	1.7
15/12	84.0	37.8	5.7	5.7	4.6	100.0%	12.7			
16/12	84.0	37.8	0.0	0.0	4.6	100.0%	17.3	5	20.0	2.7
20/12	84.0	37.8	5.8	5.8	4.6	100.0%	12.5			
21/12	84.0	37.8	0.0	0.0	4.6	100.0%	17.1	5	20.0	2.9
25/12	84.0	37.8	5.7	5.7	4.6	100.0%	12.6			
26/12	84.0	37.8	0.0	0.0	4.6	100.0%	17.1	5	20.0	2.9
30/12	84.0	37.8	2.2	2.2	4.5	100.0%	16.0			
31/12	84.0	38.1	0.0	0.0	4.5	100.0%	20.5	5	20.0	0.0
1/1	84.0	38.4	4.9	0.5	4.6	100.0%	4.6			
5/1	84.0	39.5	0.0	0.0	4.5	100.0%	22.6	5	20.0	0.0
6/1	84.0	39.8	4.9	2.6	4.5	100.0%	4.5			
10/1	84.0	40.9	0.0	0.0	4.4	100.0%	22.2	5	20.0	0.0
11/1	84.0	41.2	4.9	2.2	4.4	100.0%	4.4			
Total			49.0	39.6	393.5	100.0%			380.0	34.9

Even though water was distributed in rotation among the members in the project, the interval of water distribution, unlimited availability of water and taking water as a free resource with the wrong perception of farmers about the depth of water applying, they were favored to apply excess water to their fields.

5 SUMMARY AND CONCLUSION

Summary

This study attempted to introduce the concept of comparative performance indicators with some process indicators such as application, storage and distribution efficiencies as a tool to evaluate the performance of small-scale irrigations selected in the Upper Awash valley. Batu Degaga and Doni irrigation project were the two-selected study sites that are located in the Valley. These schemes were selected based on their proximity to Melkassa Research Center, availability of secondary data and organizational set up.

Primary field data collection were made and it included: frequent field observations, measurements of canal water flow at the diversion of Doni and pump discharge of Batu Degaga, determination of moisture contents of the soils of the selected irrigation fields before and after irrigations and using three inches parshal flumes depth of water applied to the specific areas of fields were determined.

The secondary data collection has been carried out in collaboration with organizations and government officials. The secondary data include total yields, farm gate prices of irrigated crops, area irrigated per crop per season or per year, crop types, O & M, incomes generated by the irrigation associations and cropping pattern.

To estimate the CWR, irrigation scheduling and IR of the irrigated crops at field levels and the irrigation project as a whole the CropWat for windows computer program (CropWat 4 Windows Version 4.2) was used.

The comparative indicators rely on the availability of secondary data. Getting complete data required to calculate all the external indicators (the nine indicators) for each small-scale irrigation project was very difficult. Hence, to compare the two-irrigation projects minimum sets of external indicators were applied with the available information and comparative analyses were made within and across the irrigation projects.

From the analyses of the indicators, the result of the ratios of RWS and RIS were 2.32 and 2.57 for Batu Degaga while 2.24 and 2.76 for Doni irrigation projects, respectively. The values of WDC and GRI were in the order of 0.77 and 13.60% for Batu Degaga, 1.83 and 27.55% are for Doni.

Outputs per cropped area of the two projects were more or less equal but the value of the output per command area of Doni was greater than the value of Batu Degaga. The output per unit irrigation supply for Batu Degaga was 1.14 while Doni was 0.67. Output per water consumed varies from 2.45 to 1.14 birr per m^3 for Batu Degaga and Doni respectively.

The FSS of the Batu Degaga was in the ranges of 50.96% to 217.83% and FSS of Doni was in the ranges of 85.25% to 970.49%.

In order to evaluate the irrigation water use efficiency of farmers at field level and to compare each other in the same irrigation projects three farmers were selected from each irrigation projects in relation to their location (From the head, middle and tail end water users). The parameters used to compare the efficiencies at field level were application, storage and distribution efficiencies.

The application efficiencies of the selected farmer's field from the two irrigation projects varied from 31.46% to 64.29% and storage efficiencies were in the order of 80.41% to 104.70%. Distribution efficiency of the entire selected field was 100%.

Conclusion

The evaluation and characterization of the two irrigation projects individually indicated that irrigation water was not a constraint at farm level and higher amount of water was diverted (generous supply of water) at Doni than Batu. And at Doni there was also high rate of return on investment than Batu Degaga.

Regarding the output per area, Doni was better than Batu Degaga, but for the output per water supply the inverse was true that was Batu Degaga (where water is a constraint) was better than Doni.

Trend analysis might give an indication on how the two irrigation systems are different in their irrigation system, operation and management, and so on.
Since the intention of the analysis was to investigate how consistent or how the performance of the irrigation projects were consistent with respect to the irrigation system, Doni irrigation has been performing better than Batu. But it does not mean that diversion is more efficient or healthier than pump irrigation, because it needs larger sample study and taking into consideration several situations or issues. For instance farmers' awareness, design and operational aspects of the project, market conditions and so on.

From the study of the irrigation projects, pump failure has been a serious problem next to its running cost at Batu Degaga irrigation project and it needs skilled manpower.

Irrigation of Diversion weir (at Doni) is better than Pump (Batu) for FMIS for its low operation and maintenance costs. As an opinion, advantage of Pump irrigation over Diversion weir was that the pump system can be used as a tool to force the farmers to improve or change their perception about irrigation water that it has costs and must be used efficiently.

Individual farmer's field

The three selected irrigated fields at Batu Degaga can be considered as 'in the order of similar condition' for their irrigation water management efficiencies. But at Doni, the three plots for irrigation water, Field II was more efficient than Field I. Field III was the least efficient.

From the analyses irrigation water efficiencies as a whole, farmers were doing good job in terms of water distribution uniformity. This does not mean that they were using the water efficiently; there is room for improvement.

There was a marked deficiency in irrigation water management plot level at both irrigation projects. Low efficiencies were achieved because applications far exceed farmers' management know-how. This was due to the fact that the system permitted farmers to apply large volumes of water to their plots combined with poor knowledge about the crop water requirements of the farmers.

The values of application efficiencies at field levels were reflected on the values of relative water supply of the irrigation projects as a whole. So there is some common ground to use them integrally. Even if it needs intensive data collection and close monitoring, irrigation water use efficiencies evaluations were good for farmers' field level.

Distribution efficiencies were high. The possible reason can be the layout of the furrows. The other advantage of these furrows is that a single farmer can control and irrigate the whole field without any problem.

The study covered the minimum set of indicators that can be used to evaluate the health of a system (IWMI). The small number of samples cannot permit a deep analysis of the indicators but the study showed the usefulness of the indicators. The method can be a useful tool in performance measurement and in the detection of possible improvements needed.

This paper can be considered as a starting point to evaluate the performance of small-scale irrigation systems in Ethiopia and tried to demonstrate the application of the method developed by IWMI on the two selected irrigation projects. And as this paper is the result of two irrigation projects, further evaluation has to be carried out in some other places so as to adopt and correlate these indicators with irrigation efficiencies.

6 RECOMMENDATIONS AND METHODOLOGICAL LESSONS

Recommendations

At Batu Degaga farmers have to increase the capacities of their pumps in order to meet crop water demands at peak requirement. Additional pumps are required to rehabilitate the Batu irrigation project to its full productive capacity of irrigable area, i.e., 140 ha. For this and other reasons, designing and constructing irrigation projects have to be made with care and has to consider the capacity and knowledge of the farmers.

Huge amount of money have been invested to construct the structures. And farmers are expected to use the water efficiently. Even though there was no sign of being unproductive from the time of the irrigation establishment, irrigation water was considerably wasted by the farmers themselves, especially at Doni. Farmers should be advised to grow high value cash crops than cereals so as to get much return from the production.

Most irrigation water efficiency studies were focused on long furrows so further study about the furrow hydraulics of very short traditional furrows layout, like Doni and Batu irrigation Projects, is crucial.

From the study of the farmers fields the distribution efficiencies were good while application efficiencies were poor. So in order to improve the efficiency of these furrow layouts irrigation scheduling has to be made and recommended for the farmers.

Even if the layout of the furrows at the projects has advantages on irrigation management and water distribution efficiency there was some indicators of salt accumulation in the furrows (Appendix H: Fig H-4). So further investigation has to be made.

To evaluate very short furrows of small-scale irrigations, storage efficiency can be used with application efficiency than distribution efficiency. Storage efficiency can tell us losses of water through deep percolation, because distribution efficiencies are not problems of short furrows.

Comparative indicators are very good estimator and indicator of performance of irrigation projects as a whole but full, reliable and consistent documentation system is a must. And this type of study has to be adopted and practiced on some other small-scale irrigation projects in the country.

Assigning DA and Office assistant for the WUA have a paramount importance to the improvement of irrigation projects and used as a mechanism to develop a healthy perception of farmers about irrigation.

Prior to developing an irrigation projects for farmers, the capability of farmers whether they manage it or not must be considered. And close monitoring should be practiced than completely left the operation for the farmers. Especially issues like crop water requirements have to give much emphasis.

Methodological lessons

Problems when calculating discharge, production cost, income and yields were encountered at each location. The perennial crops grown at Doni covers considerable irrigable land (around 30 ha) and consumes large volume of water but their production and income generated by the farmers was not recorded and even these farmers did not pay for the association. Ignoring these cops for the evaluation was not advisable so to collect the area coverage, interpolate incomes gained by the farmers needed additional time.

There was delay of payments by the farmers. So some payments were transferred to the next season or year so financial analysis was evaluated based on the records being available during the study. For effective financial analysis, the help of skilled personnel, clear and on time records are essential.

When calculating the gross return on investment, is it birr/ha/year basis or simply total cost divided by the irrigable area? And again the developed area and actually irrigated area were not equal, so the decision was left for the researcher.

Farmers did not have constant or consistent irrigation intervals for their crops. With the time interval of water availability, they may irrigate within 2 or 3 three days differences from the fixed irrigation intervals. So taking the average was the only option.

The ability to analyze financial dimensions of the system depends on the availability of a quantitative record. Maintaining these records and using them can assist the user group in understanding how to respond to issues and problems by facilitating a quantitative analysis of cause and effect. Information related to yield, selling price, type of crop grown, name and numbers of members, the size of land held by each farmer, and membership fee are relatively well documented at Batu Degaga. Information about the irrigation water diverted, the layout of the scheme, the design of the scheme, and the running costs of individual farmer etc were very difficult to obtain at both projects. So, to interpret and understand these records, the support of the DA at both study area was very helpful.

The development of the irrigation project at Doni was almost exclusively focused on constructing the head works and primary canal. The users were expected to construct secondary and tertiary canals themselves. At Doni the layout of the canals is different from that of the Batu Degaga. The earthen primary canal is very long and it does not have uniform cross sectional area.

Farmers are diverting water from the primary canal directly to their fields as their need. Most of the farmer uses more than one diversion ditches to irrigate their land, so it is difficult to install a single parshal flume to measure the amount of water applied to the field. Besides, farmers may change the location and the direction of the ditches frequently within a single cropping season.

Irrigation projects did not construct based on their design or the design was not realistic. Both irrigation projects studied have much higher irrigable areas than actually irrigated. This fact was reflected on the gross return on investment of the two irrigation projects studied. So designers and sponsoring agencies have to consider such condition when they develop small-scale irrigation projects.

Overlap of seasonal cropping calendar: every farmer has his own cropping calendar and at any time in a given year one can get a number of cultivated irrigable lands in the irrigation scheme. This makes difficult to estimate exactly the total amount of water diverted and total yield produced for a given cropping season.

Research process and results: the concept of evaluating small-scale irrigation system using the comparative performance indicators is a new concept in Ethiopia. During preliminary survey and data collection process there were some difficulties in obtaining necessary data and there was also problems of interpreting the type of information include in the analyses. Reports of similar works of other countries played a great role in order to solve the problem.

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8 APPENDICES

Appendix A. Comparative performance indicators

The ***Standardized Gross Value of Production (SGVP)*** was developed for cross-system comparison, as obviously there are differences in local prices at different locations throughout the world. To obtain SGVP, equivalent yield is calculated based on local prices of the crops grown, compared to the local price of the predominant, locally grown, internationally traded base crop. The second step is to value this equivalent production at world prices.

$$SGVP = \left(\sum_{crops} A_i Y_i \frac{P_i}{P_b} \right) P_{world}$$

Where,

SGVP is the standardized gross value of production,

Y_i is the yield of crop i,

P_i is the local price of crop i,

P_{world} is the value of the base crop traded at world prices,

A_i is the area cropped with crop i, and

P_b is the local price of the base crop.

Nine indicators are developed related to the irrigation and irrigated agricultural system. The main output considered is crop production, while the major inputs are water, land, and finances.

Indicators of Irrigated Agricultural Output

The four basic comparative performance indicators relate output to unit land and water. These “external” indicators provide the basis for comparison of irrigated agriculture performance. Where water is a constraining resource, output per unit water may be more important, whereas if land is a constraint relative to water, output per unit land may be more important.

Output per unit of irrigation water supplied and output per unit of water consumed are derived from a general water accounting framework (Molden et al, 1998). The water consumed is the volume of process consumption, in this case evapotranspiration. It is important to distinguish this from another important water accounting indicator—output per unit total consumption, where total consumption includes water depletion from the hydrologic cycle through process consumption (ET), other evaporative losses (from fallow land, free water surfaces, weeds, trees), flows to sinks (saline groundwater and seas), and through pollution.

We are interested in the measurement of production from irrigated agriculture that can be used to compare across systems. If only one crop is considered, production could be compared in terms of mass. The difficulty arises when comparing different crops, say wheat and tomato, as 1 kg of tomato is not readily comparable to 1 kg of wheat. When only one irrigation system is considered, or irrigation systems in a region where prices are similar, production can be measured as net value of production and gross value of production using local values.

$$Output\ per\ cropped\ area = \frac{Production}{Irrigated\ Cropped\ area}$$

$$Output\ per\ unit\ command\ area = \frac{Production}{Command\ area}$$

$$Output\ per\ irrigation\ supply = \frac{Production}{Diverted\ irrigtion\quad supply}$$

$$Output\ per\ unit\ water\ consumed = \frac{Production}{Volume\ of\ water\ consumed\ by\ ET}$$

Where,

Production is the output of the irrigated area in terms of gross or net value of production measured at local or world prices,

Irrigated cropped area is the sum of the areas under crops during the time period of analysis,

Command area is the nominal or design area to be irrigated,

Diverted irrigation supply is the volume of surface irrigation water diverted to the command area, plus net removals from groundwater, and

Volume of water consumed by ET is the actual evapotranspiration of crops.

Five additional indicators were identified in this minimum set for comparative purposes. These are meant to characterize the individual system with respect to water supply and finances.

Relative water supply and relative irrigation supply are used as the basic water supply indicators:

$$Relative\ \ water\ \ supply\ = \frac{Total\ \ water\ \ supply}{Crop\ \ demand}$$

$$Relative\ \ irrigation\ \ supply = \frac{Irrigation\ \ supply}{Irrigation\ \ demand}$$

Where:

Total water supply = Surface diversions plus net groundwater draft plus rainfall.

Crop demand = Potential crop ET, or the ET under well-watered conditions.

Irrigation supply = only the surface diversions and net groundwater draft for irrigation.

Irrigation demand = the crop ET less effective rainfall.

Relative irrigation supply is the inverse of the irrigation efficiency Molden et al (1998). The term *relative irrigation supply* was presented to be consistent with the term relative water supply, and to avoid any confusing value judgments inherent in the word *efficiency*.

Both RWS and RIS relate supply to demand, and give some indication as the condition of water abundance or scarcity, and how tightly supply and demand are matched. Care must be taken in the interpretation of results: an irrigated area upstream in a river basin may divert much water to give adequate supply and ease management, with the excess water providing a source for downstream users. In such circumstances, a higher RWS in the upstream project may indicate appropriate use of available water, and a lower RWS would actually be less desirable. Likewise, a value of 0.8 may not represent a problem; rather it may provide an indication that farmers are practicing deficit irrigation with a short water supply to maximize returns on water.

$$Water\ delivery\ capacity(\%) = \frac{Canal\ capacity\ to\ deliver\ water\ at\ system\ head}{Peak\ consumptive\ demand}$$

Where:

Capacity to deliver water at the system head = the present discharge capacity of the canal at the system head, and

Peak consumptive demand = the peak crop irrigation requirements for a monthly period expressed as a flow rate at the head of the irrigation system.

Water delivery capacity is meant to give an indication of the degree to which irrigation infrastructure is constraining cropping intensities by comparing the canal conveyance capacity to peak consumptive demands. Again, a lower or higher value may not be better, but needs to be interpreted in the context of the irrigation system, and in conjunction with the other indicators.

Financial Indicators

The two financial indicators are:

$$Gross\ \ return\ \ \ on\ Investment\ \ (\%) = \frac{Production}{Cost\ \ of\ \ irrigation\ \ \ structure}$$

$$Financial\ \ self\ \ sufficency\ = \frac{Revenue\ \ from\ Irrigation\ \ service\ \ fees}{Total\ \ O\ \&\ M\ \ expenditur\ e}$$

Where,

Cost of irrigation infrastructure considers the cost of the irrigation water delivery system referenced to the same year as the SGVP,

Revenue from irrigation, is the revenue generated, either from fees, or other locally generated income, and

Total O & M expenditure is the amount expended locally through operation and management

Policy makers are keenly interested in the returns to investments made. Similarly, researchers would like to be able to recommend systems that yield acceptable returns within a given environment. Large irrigation investments are made in irrigation infrastructure, thus returns compared to investment in infrastructure are presented here. We focus on water delivery infrastructure to be able to analyze differences between various types of delivery systems such as structured, automated, lined, and unlined canal sections. Infrastructure related to river diversions, storage, and drainage is not included here, because of the desire to be able to compare different methods of water delivery. Also, diversion and storage works often serve other non-irrigation purposes so their costs cannot be entirely allocated to irrigation. The cost of the distribution system can either be estimated from original costs, or estimated by using present costs of similar types of infrastructure development.

Financial self-sufficiency tells us what percent of expenditures on O&M is generated locally. If government subsidizes O&M heavily, financial self-sufficiency would be low, whereas if local farmers through their fees pay for most of the O&M expenditures, financial self-sufficiency would be high. Financial self-sufficiency does not tell us the O&M requirement, only the expenditures. A high value of financial self-sufficiency does not automatically indicate a sustainable system, as the O&M expenditures might be too low to meet the actual maintenance needs.

Appendix B. Surface water and small-scale irrigation status in Ethiopia

Table B-1. Ethiopian surface water resources by major river basins

No.	River basin	Catchments area (km^2)	Annual run off (10^9 m^3)	Specific discharge (litres/km^2)	Irrigation potential (ha)
1	Abay	199,812,112.00	52.60	7.8	711,000
2	Awash	112,700.00	4.60	1.4	206,000
3	Baro-Akobo	74,100.00	23.60	9.7	483,000
4	Genale-Dawa	171,050.00	5.88	1.2	326,000
5	Mereb	5,900.00	0.26	3.2	38,000
6	Omo-Ghibe	78,200.00	17.96	6.7	348,000
7	Rift Valley	52,740.00	5.64	3.4	46,500
8	Tekeze	90,000.00	7.63	3.2	302,000
9	Wabi-Shebele	200,214.00	3.16	0.5	122,000
10	Danakil	74,000.00	0.86	0	-

Table B-2 The Potential Area for and Actual Status of Small-Scale Irrigation in Ethiopia

Reference source	*Potential Irrigable Area (hectares)*	*Actual Irrigated Area (hectares)*		*Notes/Observations*
CSA (1998)	-----	95/96 84,640	96/97 68,210	Meher (main rainy) season
AQUASTAT (1998)	165,000 - 400,000	63,581		An online database supported by (1998) FAO. Raises issue of need for rehabilitation
MWR	180,000	64,000		Notes that some schemes are not functioning and in need of rehabilitation
Tahal (1998)	-----	40,270		Traditional Schemes only- those without assistance from outside the community
IDD/MOA (1993)	352,000	70,000		Estimate of traditional irrigation without external assistance
FAO	270,000	-----		Potential for SSI using both ground water and surface water sources

Source: Tom et al, 1999

Appendix C Relations of soil type and soil moisture contents

Table C-1. Range of readily available soil moisture for different soil types, % of moisture based on dry weight of soil (ICE, 1983)

Soil type	*Field capacity*	*Permanent wilting point*	*Available water per unit depth of soil, mm/m*
Fine sand	3- 5	1- 3	20- 40
Sandy loam	5-15	3- 8	40-110
Silt loam	12-18	6-10	60-130
Clay loam	15-30	7-16	100-180
Clay	25-40	12-20	160-300

Table C-2 Typical soil water characteristics for different soil types

Source: Richard et al (1998)

Soil type (USA Soil Texture Classification)	*Soil water characteristics*		
	èFC	èWP	(èFC - èWP)
	m^3/m^3	m^3/m^3	m^3/m^3
Sand	0.07 - 0.17	0.02 - 0.07	0.05 - 0.11
Loamy sand	0.11 - 0.19	0.03 - 0.10	0.06 - 0.12
Sandy loam	0.18 - 0.28	0.06 - 0.16	0.11 - 0.15
Loam	0.20 - 0.30	0.07 - 0.17	0.13 - 0.18
Silt loam	0.22 - 0.36	0.09 - 0.21	0.13 - 0.19
Silt	0.28 - 0.36	0.12 - 0.22	0.16 - 0.20
Silt clay loam	0.30 - 0.37	0.17 - 0.24	0.13 - 0.18
Silty clay	0-30 - 0.42	0.17 - 0.29	0.13 - 0.19
Clay	0.32 - 0.40	0.20 - 0.24	0.12 - 0.20

Appendix D Climatic data of Batu Degaga and Doni irrigation projects

Table D-1 Monthly climatic data used for determination of CWR for Batu Degaga

Country : Ethiopia Station : Batu Degaga
Altitude: 1342 meter(s) above M.S.L.
Latitude: 8.43 Deg. (North) Longitude: 39.41 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)
January	26.9	12.0	48.0	250.6	8.8	20.6	5.28
February	30.5	13.5	49.0	259.2	9.3	22.6	6.17
March	30.6	15.3	49.0	285.1	8.2	22.0	6.44
April	29.4	15.9	54.0	241.9	7.7	21.4	5.73
May	33.0	14.0	39.0	233.3	9.6	23.7	6.82
June	30.1	16.6	53.0	267.8	8.4	21.4	5.98
July	25.9	11.5	68.0	276.5	6.1	18.1	4.57
August	25.6	16.2	71.0	198.7	6.0	18.4	4.12
September	26.7	15.0	69.0	155.5	7.2	20.4	4.34
October	29.2	11.7	43.0	267.8	9.8	23.6	6.35
November	28.5	12.6	41.0	337.0	9.7	22.1	6.57
December	26.2	11.4	48.0	293.8	9.4	20.9	5.45
Average	28.6	13.8	52.7	255.6	8.3	21.3	5.65

Pen-Mon equation was used in ETo calculations with the following values for Angstrom's Coefficients: a = 0.25 b = 0.5

Table D-2 Monthly data of rainfall and ET_o for Batu Degaga

Month	ETo (mm/d)	Total Rainfall (mm/month)	Effective Rain (mm/month)
January	5.28	16.6	16.2
February	6.17	24.2	23.3
March	6.44	128.1	101.8
April	5.73	70.8	62.8
May	6.82	4.0	4.0
June	5.98	47.7	44.1
July	4.57	197.3	135.0
August	4.12	183.8	129.7
September	4.34	158.8	118.5
October	6.35	0.0	0.0
November	6.57	1.3	1.3
December	5.45	53.1	48.6
Total (mm/Year)	2061.29	885.7	685.3

N.B. Effective rainfall calculated using the USSCS formulas:
Effective R. = (125 - 0.2 * Total R.)* Total R. / 125 ... ... (Total R. < 250 mm/month),
Effective R. = 0.1 * Total R. - 125 ... (Total R. > 250 mm/month).

Table D-3 Monthly climatic data used for determination of CWR for Doni

Country : Ethiopia Station : Doni
Altitude: 1260 meter(s) above M.S.L.
Latitude: 8.51 Deg. (North) Longitude: 39.55 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)
January	29.4	14.8	53.4	112.1	8.3	19.9	4.26
February	32.6	15.4	46.4	133.9	8.2	20.9	5.12
March	33.6	17.7	45.6	154.6	8.0	21.7	5.70
April	33.7	19.2	48.2	143.8	8.5	22.6	5.74
May	35.7	17.8	35.0	121.7	8.8	22.5	5.71
June	34.4	20.6	44.1	170.6	8.2	21.1	5.93
July	31.3	19.8	53.6	258.5	7.3	19.9	5.91
August	30.8	19.1	58.0	187.2	7.5	20.7	5.32
September	31.4	18.8	57.3	124.1	7.5	20.8	4.92
October	33.3	14.6	39.1	106.8	9.1	22.5	5.11
November	31.0	14.4	44.3	120.0	9.3	21.5	4.76
December	29.0	13.0	46.5	110.6	8.9	20.2	4.22
Average	32.2	17.1	47.6	145.3	8.3	21.2	5.22

Pen-Mon equation was used in ETo calculations with the following values for Angstrom's Coefficients: a = 0.25 b = 0.5

Table D-4 Monthly data of rainfall and ET_o for Doni

Month	ETo (mm/d)	Total Rainfall (mm/month)	Effective Rain (mm/month)
January	4.26	27.8	26.6
February	5.12	41.4	38.7
March	5.70	47.0	43.5
April	5.74	23.6	22.7
May	5.71	1.6	1.6
June	5.93	82.4	71.5
July	5.91	112.3	92.1
August	5.32	240.9	148.0
September	4.92	70.2	62.3
October	5.11	0.0	0.0
November	4.76	3.7	3.7
December	4.22	35.0	33.0
Total (mm/Year)	1906.99	685.9	543.7

N.B. Effective rainfall calculated using the USSCS formulas:
Effective R. = (125 - 0.2 * Total R.)* Total R. / 125 ...
... (Total R. < 250 mm/month),
Effective R. = 0.1 * Total R. - 125 .. (Total R. > 250 mm/month).

Appendix E. CWR and irrigation scheduling of dominant crops at Batu Degaga based on farmers irrigation intervals, planting dates and 45% irrigation efficiency.

Table E-1 Crop water requirements for small Vegetables (onion)

```
***************************************************************************
                         Crop Water Requirements Report
***************************************************************************
- Crop  # 1             : Small Vegetable
- Planting date         : 28/10
- Calculation time step = 8 Day(s)
- Irrigation Efficiency = 45%
---------------------------------------------------------------------------
```

Date	ETo	Planted Area	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS
	(mm/period)	(%)		(mm/period)	(mm/period)	(mm/period)	(mm/period)	l/s/ha
28/10	40.91	100.00	0.70	28.64	0.00	0.00	28.64	0.92
5/11	41.47	100.00	0.70	29.03	0.00	0.00	29.03	0.93
13/11	42.04	100.00	0.71	30.04	0.00	0.00	30.04	0.97
21/11	42.58	100.00	0.80	34.03	1.23	1.14	32.90	1.06
29/11	43.10	100.00	0.89	38.47	8.83	8.06	30.41	0.98
7/12	43.56	100.00	0.99	42.95	12.99	11.87	31.08	1.00
15/12	43.97	100.00	1.05	46.10	13.39	12.28	33.82	1.09
23/12	44.29	100.00	1.05	46.50	11.47	10.59	35.91	1.15
31/12	44.77	100.00	1.05	47.01	6.09	5.99	41.02	1.32
8/1	46.00	100.00	1.05	48.30	2.39	2.39	45.91	1.48
16/1	47.18	100.00	1.02	48.11	0.64	0.64	47.48	1.53
24/1	42.15	100.00	0.97	40.89	0.80	0.80	40.09	1.47
Total	522.02			480.08	57.82	53.75	426.33	1.15

```
---------------------------------------------------------------------------
* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
***************************************************************************
```

Table E-2 Irrigation scheduling for small Vegetables (onion)

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Irrigation Scheduling Report

****

* Crop Data: Small Vegetable Planting date: 28/10
- Application Timing: irrigate each 8days.
- Applications Depths: Fixed depths of 40mm each.
- Start of Scheduling: 28/10

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
28/10	25.0	7.5	0.0	0.0	1.3	35.7%	20.0	0	40.0	20.0
5/11	30.6	9.9	0.0	0.0	1.7	78.5%	22.5	8	40.0	17.5
13/11	36.2	12.6	0.0	0.0	2.1	85.4%	24.8	8	40.0	15.2
21/11	41.8	15.5	0.0	0.0	2.6	90.0%	27.4	8	40.0	12.6
25/11	44.6	17.1	1.9	1.9	4.3	100.0%	14.8			
29/11	47.4	18.8	0.0	0.0	3.2	87.0%	30.3	8	40.0	9.7
30/11	48.1	19.2	5.3	0.0	4.6	100.0%	4.6			
5/12	51.6	21.4	7.4	7.4	5.0	100.0%	21.5			
7/12	53.0	22.3	0.0	0.0	4.4	93.1%	30.9	8	40.0	9.1
10/12	55.1	23.6	8.4	8.4	5.3	100.0%	7.4			
15/12	58.6	26.0	8.5	8.5	5.7	100.0%	26.6	8	40.0	13.4
20/12	60.0	27.0	8.0	8.0	5.8	100.0%	20.8			
23/12	60.0	27.0	0.0	0.0	4.8	94.5%	37.3	8	40.0	2.7
25/12	60.0	27.0	7.1	5.8	5.8	100.0%	5.8			
30/12	60.0	27.0	2.5	2.5	5.8	100.0%	32.4			
31/12	60.0	27.0	0.0	0.0	4.9	83.7%	37.3	8	40.0	2.7
1/1	60.0	27.0	3.8	0.0	5.8	100.0%	5.8			
6/1	60.0	27.0	2.3	2.3	5.9	100.0%	32.9			
8/1	60.0	27.0	0.0	0.0	4.0	74.6%	41.8	8	40.0	0.0
11/1	60.0	27.0	1.2	1.2	6.0	100.0%	18.7			
16/1	60.0	27.2	0.5	0.5	3.7	84.2%	43.8	8	40.0	0.0
21/1	60.0	28.2	0.3	0.3	6.0	100.0%	33.6			
24/1	60.0	28.8	0.0	0.0	3.3	69.1%	45.9	8	40.0	0.0
26/1	60.0	29.2	0.7	0.7	5.9	100.0%	17.0			
Total			57.8	47.4	445.2	92.7%			480.0	102.8

Table E-3 Crop water requirements for maize

```
***************************************************************************
                         Crop Water Requirements Report
***************************************************************************
- Crop  # 1              : MAIZE  (Grain)
- Block #                : [All blocks]
- Planting date          : 6/11
- Calculation time step = 9 Day(s)
- Irrigation Efficiency = 45%
---------------------------------------------------------------------------
Date     ETo      Planted  Crop     CWR      Total   Effect.   Irr.     FWS
                   Area     Kc      (ETm)    Rain     Rain     Req.
      (mm/period) (%)               ---------- (mm/period) ---------  l/s/ha
---------------------------------------------------------------------------
6/11    46.78    100.00   0.30     14.03    0.00     0.00     14.03    0.40
15/11   47.48    100.00   0.30     14.25    0.00     0.00     14.25    0.41
24/11   48.16    100.00   0.31     14.81    4.83     4.42     10.39    0.30
3/12    48.79    100.00   0.46     22.33    13.14    11.99    10.34    0.30
12/12   49.33    100.00   0.66     32.57    15.24    13.96    18.60    0.53
21/12   49.76    100.00   0.86     42.93    13.42    12.37    30.55    0.87
30/12   50.32    100.00   1.07     53.61    7.37     7.18     46.44    1.33
8/1     51.83    100.00   1.20     62.07    2.53     2.53     59.54    1.70
17/1    53.31    100.00   1.20     63.97    0.63     0.63     63.34    1.81
26/1    54.61    100.00   1.20     65.53    1.85     1.85     63.68    1.82
4/2     55.69    100.00   1.20     66.83    6.24     5.81     61.02    1.74
13/2    56.53    100.00   1.18     66.95    13.18    11.09    55.86    1.60
22/2    57.11    100.00   1.01     57.86    21.45    17.46    40.40    1.15
3/3     57.42    100.00   0.80     46.13    29.39    23.69    22.44    0.64
12/3    57.48    100.00   0.59     34.11    35.12    28.36    5.74     0.16
---------------------------------------------------------------------------
Total   784.60                     657.96   164.37   141.33   516.63  0.98
---------------------------------------------------------------------------*
ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
***************************************************************************
```

Table E-4 Irrigation scheduling for maize

```
******************************************************************************
                          Irrigation Scheduling Report
******************************************************************************
* Crop Data:                   MAIZE  (Grain)   Planting date: 6/11
- Application Timing:         Irrigate each 9days.
- Applications Depths:        Fixed depths of 55mm each.
- Start of Scheduling: 6/11
```

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
6/11	30.0	15.0	0.0	0.0	0.8	50.0%	23.3	0	55.0	31.7
15/11	39.7	19.8	0.0	0.0	1.6	100.0%	14.1	9	55.0	40.9
24/11	49.4	24.7	0.0	0.0	1.6	100.0%	14.3	9	55.0	40.7
25/11	50.5	25.2	1.9	0.0	1.6	100.0%	1.6			
30/11	55.8	27.9	5.3	5.3	1.6	100.0%	4.3			
3/12	59.1	29.5	0.0	0.0	2.0	100.0%	9.9	9	55.0	45.1
5/12	61.2	30.6	7.4	2.1	2.2	100.0%	2.2			
10/12	66.6	33.3	8.4	8.4	2.9	100.0%	6.9			
12/12	68.8	34.4	0.0	0.0	3.1	100.0%	13.0	9	55.0	42.0
15/12	72.0	36.0	8.5	6.6	3.5	100.0%	3.5			
20/12	77.4	38.7	8.0	8.0	4.1	100.0%	14.9			
21/12	78.5	39.2	0.0	0.0	4.3	100.0%	19.1	9	55.0	35.9
25/12	82.8	41.4	7.1	7.1	4.8	100.0%	11.2			
30/12	88.2	44.1	2.5	2.5	5.4	100.0%	34.5	9	55.0	20.5
1/1	90.3	45.2	3.8	3.8	5.7	100.0%	7.4			
6/1	95.7	47.8	2.3	2.3	6.4	100.0%	35.6			
8/1	97.8	48.9	0.0	0.0	6.7	100.0%	48.8	9	55.0	6.2
11/1	100.0	50.0	1.2	1.2	6.9	100.0%	19.4			
16/1	100.0	50.0	0.5	0.5	7.0	100.0%	53.7			
17/1	100.0	50.0	0.0	0.0	6.5	92.5%	60.2	9	55.0	0.0
21/1	100.0	50.0	0.3	0.3	7.1	100.0%	33.3			
26/1	100.0	50.0	0.7	0.7	5.7	93.9%	66.2	9	55.0	0.0
31/1	100.0	50.0	1.6	1.6	7.3	100.0%	45.9			
4/2	100.0	50.0	0.0	0.0	5.0	85.3%	71.0	9	55.0	0.0
5/2	100.0	50.0	3.1	3.1	7.4	100.0%	20.3			
10/2	100.0	50.0	5.0	5.0	7.5	100.0%	52.4			
13/2	100.0	50.0	0.0	0.0	5.2	81.6%	70.7	9	55.0	0.0
15/2	100.0	50.0	7.3	7.3	7.5	100.0%	23.5			
20/2	100.0	52.0	9.8	9.8	7.3	100.0%	50.9			
22/2	100.0	54.0	0.0	0.0	6.4	95.6%	64.5	9	55.0	0.0
25/2	100.0	57.0	12.4	12.4	6.6	100.0%	17.2			
2/3	100.0	62.0	15.0	15.0	5.9	100.0%	32.9			
3/3	100.0	63.0	0.0	0.0	5.7	100.0%	38.6	9	55.0	16.4
7/3	100.0	67.0	17.2	16.3	5.1	100.0%	5.1			
12/3	100.0	72.0	19.0	19.0	4.4	100.0%	9.5	9	55.0	45.5
17/3	100.0	77.0	20.2	16.1	3.6	100.0%	3.6			
Total			168.5	154.2	645.4	98.1%			825.0	325.0

Table E-5 Crop water requirements for tomato

```
***************************************************************************
                        Crop Water Requirements Report
***************************************************************************
- Crop  # 1             : TOMATO
- Block #               : [All blocks]
- Planting date         : 23/10
- Calculation time step = 5 Day(s)
- Irrigation Efficiency = 45%
---------------------------------------------------------------------------
```

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS l/s/ha
				---------- (mm/period)			---------	
23/10	25.29	100.00	0.60	15.18	0.00	0.00	15.18	0.78
28/10	25.51	100.00	0.60	15.30	0.00	0.00	15.30	0.79
2/11	25.72	100.00	0.60	15.43	0.00	0.00	15.43	0.79
7/11	25.94	100.00	0.60	15.57	0.00	0.00	15.57	0.80
12/11	26.16	100.00	0.60	15.70	0.00	0.00	15.70	0.81
17/11	26.38	100.00	0.60	15.83	0.00	0.00	15.83	0.81
22/11	26.59	100.00	0.64	17.05	0.27	0.26	16.80	0.86
27/11	26.80	100.00	0.71	19.03	3.48	3.18	15.85	0.82
2/12	26.99	100.00	0.78	21.02	6.31	5.76	15.27	0.79
7/12	27.18	100.00	0.85	23.03	7.91	7.22	15.81	0.81
12/12	27.34	100.00	0.92	25.06	8.51	7.79	17.27	0.89
17/12	27.49	100.00	0.99	27.08	8.36	7.67	19.41	1.00
22/12	27.63	100.00	1.05	29.11	7.67	7.07	22.05	1.13
27/12	27.73	100.00	1.12	31.13	6.63	6.14	24.99	1.29
1/1	27.91	100.00	1.15	32.10	3.77	3.76	28.34	1.46
6/1	28.41	100.00	1.15	32.67	2.30	2.30	30.37	1.56
11/1	28.89	100.00	1.15	33.23	1.17	1.17	32.06	1.65
16/1	29.35	100.00	1.15	33.76	0.47	0.47	33.28	1.71
21/1	29.79	100.00	1.15	34.26	0.29	0.29	33.96	1.75
26/1	30.19	100.00	1.15	34.72	0.67	0.67	34.05	1.75
31/1	30.55	100.00	1.15	35.14	1.60	1.60	33.54	1.73
5/2	30.88	100.00	1.15	35.51	3.07	2.94	32.57	1.68
10/2	31.17	100.00	1.15	35.84	5.00	4.40	31.44	1.62
15/2	31.41	100.00	1.12	35.02	7.30	6.14	28.88	1.49
20/2	31.61	100.00	1.06	33.40	9.83	8.08	25.31	1.30
25/2	31.76	100.00	1.00	31.70	12.44	10.11	21.60	1.11
2/3	31.86	100.00	0.94	29.95	14.97	12.08	17.87	0.92
7/3	31.92	100.00	0.88	28.15	17.22	13.87	14.28	0.73
12/3	31.94	100.00	0.82	26.30	19.02	15.34	10.96	0.56
Total	830.42			777.26	148.27	128.30	648.96	1.15

```
---------------------------------------------------------------------------*
ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
***************************************************************************
```

Table E-6 Irrigation scheduling for tomato

Irrigation Scheduling Report

* Crop Data: Crop : TOMATO Planting date: 23/10
- Application Timing: Irrigate each 5days.
- Applications Depths: Fixed depths of 30mm each.
- Start of Scheduling: 23/10

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
23/10	25.0	7.5	0.0	0.0	1.1	35.7%	19.8	0	30.0	10.2
28/10	30.4	9.3	0.0	0.0	2.6	97.2%	14.8	5	30.0	15.2
2/11	35.7	11.2	0.0	0.0	2.9	99.2%	15.2	5	30.0	14.8
7/11	41.1	13.2	0.0	0.0	3.1	100.0%	15.5	5	30.0	14.5
12/11	46.4	15.3	0.0	0.0	3.1	100.0%	15.6	5	30.0	14.4
17/11	51.8	17.4	0.0	0.0	3.2	100.0%	15.7	5	30.0	14.3
22/11	57.1	19.6	0.0	0.0	3.3	100.0%	15.9	5	30.0	14.1
25/11	60.4	21.0	1.9	1.9	3.5	100.0%	8.3			
27/11	62.5	21.9	0.0	0.0	3.6	100.0%	15.5	5	30.0	14.5
30/11	65.7	23.3	5.3	5.3	3.9	100.0%	6.1			
2/12	67.9	24.2	0.0	0.0	4.0	100.0%	14.1	5	30.0	15.9
5/12	71.1	25.7	7.4	7.4	4.3	100.0%	5.2			
7/12	73.2	26.7	0.0	0.0	4.4	100.0%	14.0	5	30.0	16.0
10/12	76.4	28.2	8.4	8.4	4.7	100.0%	5.4			
12/12	78.6	29.2	0.0	0.0	4.8	100.0%	15.1	5	30.0	14.9
15/12	81.8	30.7	8.5	8.5	5.1	100.0%	6.5			
17/12	83.9	31.8	0.0	0.0	5.3	100.0%	17.0	5	30.0	13.0
20/12	87.1	33.4	8.0	8.0	5.5	100.0%	8.3			
22/12	89.3	34.4	0.0	0.0	5.7	100.0%	19.5	5	30.0	10.5
25/12	92.5	36.1	7.1	7.1	5.9	100.0%	10.4			
27/12	94.6	37.2	0.0	0.0	6.1	100.0%	22.4	5	30.0	7.6
30/12	97.9	38.9	2.5	2.5	6.3	100.0%	16.2			
1/1	100.0	40.0	3.8	3.8	6.4	100.0%	25.2	5	30.0	4.8
6/1	100.0	40.0	2.3	2.3	6.5	100.0%	29.9	5	30.0	0.1
11/1	100.0	40.0	1.2	1.2	6.6	100.0%	31.6	5	30.0	0.0
16/1	100.0	40.0	0.5	0.5	6.7	100.0%	34.5	5	30.0	0.0
21/1	100.0	40.0	0.3	0.3	6.8	100.0%	38.0	5	30.0	0.0
26/1	100.0	40.0	0.7	0.7	6.9	100.0%	41.7	5	30.0	0.0
31/1	100.0	40.0	1.6	1.6	7.0	100.0%	44.9	5	30.0	0.0
5/2	100.0	40.0	3.1	3.1	7.1	100.0%	47.1	5	30.0	0.0
10/2	100.0	40.0	5.0	5.0	7.1	99.8%	47.6	5	30.0	0.0
15/2	100.0	40.3	7.3	7.3	7.1	100.0%	46.1	5	30.0	0.0
20/2	100.0	42.0	9.8	9.8	6.8	100.0%	41.0	5	30.0	0.0
25/2	100.0	43.7	12.4	12.4	6.5	100.0%	31.6	5	30.0	0.0
2/3	100.0	45.3	15.0	15.0	6.1	100.0%	18.0	5	30.0	12.0
7/3	100.0	47.0	17.2	17.2	5.8	100.0%	12.4	5	30.0	17.6
12/3	100.0	48.7	19.0	19.0	5.4	100.0%	8.8	5	30.0	21.2
Total			148.3	148.3	774.7	99.7%			870.0	245.7

Table E-7 Crop water requirements for sweet pepper

****

Crop Water Requirements Report

****

- Crop # 1 : Sweet Peppers
- Block # : [All blocks]
- Planting date : 3/11
- Calculation time step = 5 Day(s)
- Irrigation Efficiency = 45%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS l/s/ha
3/11	25.77	100.00	0.60	15.46	0.00	0.00	15.46	0.80
8/11	25.99	100.00	0.60	15.59	0.00	0.00	15.59	0.80
13/11	26.21	100.00	0.60	15.72	0.00	0.00	15.72	0.81
18/11	26.42	100.00	0.60	15.85	0.00	0.00	15.85	0.82
23/11	26.64	100.00	0.60	15.98	0.67	0.62	15.36	0.79
28/11	26.84	100.00	0.60	16.10	4.16	3.80	12.31	0.63
3/12	27.03	100.00	0.63	17.13	6.72	6.13	11.00	0.57
8/12	27.21	100.00	0.69	18.78	8.10	7.40	11.38	0.59
13/12	27.38	100.00	0.75	20.43	8.54	7.81	12.62	0.65
18/12	27.52	100.00	0.80	22.09	8.26	7.58	14.50	0.75
23/12	27.65	100.00	0.86	23.74	7.48	6.90	16.84	0.87
28/12	27.74	100.00	0.91	25.38	6.10	5.71	19.67	1.01
2/1	28.01	100.00	0.97	27.21	3.46	3.46	23.75	1.22
7/1	28.51	100.00	1.03	29.29	2.05	2.05	27.25	1.40
12/1	28.99	100.00	1.05	30.44	0.99	0.99	29.44	1.51
17/1	29.44	100.00	1.05	30.91	0.39	0.39	30.52	1.57
22/1	29.87	100.00	1.05	31.36	0.32	0.32	31.04	1.60
27/1	30.27	100.00	1.05	31.78	0.81	0.81	30.97	1.59
1/2	30.62	100.00	1.05	32.15	1.86	1.86	30.30	1.56
6/2	30.94	100.00	1.05	32.49	3.42	3.21	29.28	1.51
11/2	31.22	100.00	1.05	32.78	5.44	4.73	28.05	1.44
16/2	31.45	100.00	1.05	33.02	7.79	6.52	26.51	1.36
21/2	31.64	100.00	1.03	32.51	10.35	8.48	24.02	1.24
26/2	31.78	100.00	0.99	31.46	12.96	10.51	20.96	1.08
3/3	31.88	100.00	0.95	30.36	15.44	12.46	17.91	0.92
8/3	31.93	100.00	0.91	29.22	17.62	14.19	15.02	0.77
Total	748.94			657.26	132.93	115.93	541.33	1.07

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

****

Table E-8 Irrigation scheduling for sweet pepper

```
**************************************************************************
                          Irrigation Scheduling Report
**************************************************************************
* Crop Data:                    Sweet Peppers     Planting date: 3/11
- Application Timing:           Irrigate each 5days.
- Applications Depths:          Fixed depths of 30mm each.
- Start of Scheduling:          3/11
--------------------------------------------------------------------------
```

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
3/11	25.0	5.0	0.0	0.0	1.0	31.3%	19.7	0	30.0	10.3
8/11	28.9	6.0	0.0	0.0	2.3	91.3%	14.1	5	30.0	15.9
13/11	32.9	7.0	0.0	0.0	2.5	94.0%	14.7	5	30.0	15.3
18/11	36.8	8.1	0.0	0.0	2.7	95.9%	15.1	5	30.0	14.9
23/11	40.7	9.3	0.0	0.0	2.8	97.6%	15.5	5	30.0	14.5
25/11	42.3	9.8	1.9	1.9	3.2	100.0%	4.4			
28/11	44.6	10.5	0.0	0.0	3.2	99.7%	14.0	5	30.0	16.0
30/11	46.2	11.0	5.3	3.2	3.2	100.0%	3.2			
3/12	48.6	11.8	0.0	0.0	3.3	100.0%	13.0	5	30.0	17.0
5/12	50.1	12.3	7.4	3.4	3.4	100.0%	3.4			
8/12	52.5	13.1	0.0	0.0	3.6	100.0%	14.1	5	30.0	15.9
10/12	54.1	13.7	8.4	3.7	3.8	100.0%	3.8			
13/12	56.4	14.5	0.0	0.0	4.0	100.0%	15.4	5	30.0	14.6
15/12	58.0	15.1	8.5	4.0	4.1	100.0%	4.1			
18/12	60.4	16.0	0.0	0.0	4.3	100.0%	16.7	5	30.0	13.3
20/12	61.9	16.5	8.0	4.4	4.4	100.0%	4.4			
23/12	64.3	17.4	0.0	0.0	4.6	100.0%	18.1	5	30.0	11.9
25/12	65.9	18.1	7.1	4.7	4.7	100.0%	4.7			
28/12	68.2	19.0	0.0	0.0	4.9	100.0%	19.4	5	30.0	10.6
30/12	69.8	19.6	2.5	2.5	5.1	100.0%	7.6			
1/1	71.4	20.3	3.8	3.8	5.2	100.0%	14.1			
2/1	72.1	20.6	0.0	0.0	5.3	100.0%	19.4	5	30.0	10.6
6/1	75.3	21.9	2.3	2.3	5.6	100.0%	19.6			
7/1	76.1	22.3	0.0	0.0	5.7	100.0%	25.3	5	30.0	4.7
11/1	79.2	23.7	1.2	1.2	6.0	100.0%	22.4			
12/1	80.0	24.0	0.0	0.0	6.0	100.0%	28.5	5	30.0	1.5
16/1	80.0	24.0	0.5	0.5	6.1	100.0%	23.9			
17/1	80.0	24.0	0.0	0.0	6.1	100.0%	30.1	5	30.0	0.0
21/1	80.0	24.0	0.3	0.3	6.2	100.0%	24.5			
22/1	80.0	24.0	0.0	0.0	6.2	99.0%	30.7	5	30.0	0.0
26/1	80.0	24.0	0.7	0.7	6.3	100.0%	25.2			
27/1	80.0	24.0	0.0	0.0	6.2	97.9%	31.4	5	30.0	0.0
31/1	80.0	24.0	1.6	1.6	6.4	100.0%	25.2			
1/2	80.0	24.0	0.0	0.0	6.3	97.8%	31.5	5	30.0	0.0
5/2	80.0	24.0	3.1	3.1	6.5	100.0%	24.2			
6/2	80.0	24.0	0.0	0.0	6.5	99.7%	30.6	5	30.0	0.0
10/2	80.0	24.0	5.0	5.0	6.5	100.0%	21.6			
11/2	80.0	24.0	0.0	0.0	6.5	100.0%	28.2	5	30.0	1.8
15/2	80.0	24.0	7.3	7.3	6.6	100.0%	18.9			
16/2	80.0	24.0	0.0	0.0	6.6	100.0%	25.5	5	30.0	4.5
20/2	80.0	24.0	9.8	9.8	6.6	100.0%	16.6			
21/2	80.0	24.8	0.0	0.0	6.6	100.0%	23.2	5	30.0	6.8

25/2	80.0	28.0	12.4	12.4	6.4	100.0%	13.5			
26/2	80.0	28.8	0.0	0.0	6.4	100.0%	19.9	5	30.0	10.1
2/3	80.0	32.0	15.0	15.0	6.2	100.0%	10.1			
3/3	80.0	32.8	0.0	0.0	6.2	100.0%	16.3	5	30.0	13.7
7/3	80.0	36.0	17.2	17.2	6.0	100.0%	7.0			
8/3	80.0	36.8	0.0	0.0	5.9	100.0%	12.9	5	30.0	17.1
12/3	80.0	40.0	19.0	17.5	5.7	100.0%	5.7			
Total			148.3	125.4	651.5	99.1%			780.0	241.0

Appendix F CWR and irrigation scheduling of dominant crops at Doni based on farmers irrigation intervals, planting dates and 45% irrigation efficiency.

Table F-1 Crop water requirements for small Vegetable (onion)

Crop Water Requirements Report

- Crop # 1 : Small Vegetable
- Planting date : 12/10
- Calculation time step = 5 Day(s)
- Irrigation Efficiency = 45%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS l/s/ha
12/10	24.40	100.00	0.70	17.08	0.00	0.00	17.08	0.88
17/10	24.15	100.00	0.70	16.91	0.00	0.00	16.91	0.87
22/10	23.92	100.00	0.70	16.74	0.00	0.00	16.74	0.86
27/10	23.69	100.00	0.70	16.58	0.00	0.00	16.58	0.85
1/11	23.46	100.00	0.74	17.24	0.00	0.00	17.24	0.89
6/11	23.25	100.00	0.79	18.44	0.00	0.00	18.44	0.95
11/11	23.04	100.00	0.85	19.62	0.00	0.00	19.62	1.01
16/11	22.84	100.00	0.91	20.79	0.00	0.00	20.79	1.07
21/11	22.66	100.00	0.97	21.94	0.12	0.12	21.81	1.12
26/11	22.48	100.00	1.03	23.08	1.93	1.84	21.24	1.09
1/12	22.31	100.00	1.05	23.43	3.64	3.43	19.99	1.03
6/12	22.16	100.00	1.05	23.26	4.78	4.51	18.76	0.96
11/12	22.01	100.00	1.05	23.11	5.47	5.15	17.96	0.92
16/12	21.88	100.00	1.05	22.97	5.78	5.46	17.52	0.90
21/12	21.76	100.00	1.05	22.85	5.82	5.50	17.35	0.89
26/12	21.65	100.00	1.05	22.73	5.66	5.36	17.38	0.89
31/12	21.99	100.00	1.03	22.64	5.03	4.79	17.86	0.92
5/1	22.40	100.00	1.00	22.32	4.89	4.67	17.66	0.91
10/1	22.76	100.00	0.96	21.93	4.93	4.71	17.22	0.89
Total	432.80			393.67	48.04	45.53	348.14	0.94

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

Table F-2 Irrigation scheduling for small Vegetable (onion)

****
Irrigation Scheduling Report
****

* Crop Data: : Small Vegetable

- Application Timing: Irrigate each 5days.
- Applications Depths: Fixed depths of 20mm each.
- Start of Scheduling: 12/10

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
12/10	35.0	10.5	0.0	0.0	3.4	100.0%	12.2	0	20.0	7.8
17/10	39.9	12.6	0.0	0.0	3.3	99.2%	16.9	5	20.0	3.1
22/10	44.8	14.8	0.0	0.0	3.4	100.0%	16.9	5	20.0	3.1
27/10	49.7	17.1	0.0	0.0	3.3	100.0%	16.7	5	20.0	3.3
1/11	54.6	19.7	0.0	0.0	3.4	100.0%	16.6	5	20.0	3.4
6/11	59.5	22.3	0.0	0.0	3.6	100.0%	17.5	5	20.0	2.5
11/11	64.4	25.1	0.0	0.0	3.8	100.0%	18.7	5	20.0	1.3
16/11	69.3	28.1	0.0	0.0	4.1	100.0%	19.9	5	20.0	0.1
21/11	74.2	31.2	0.0	0.0	4.3	100.0%	21.0	5	20.0	0.0
25/11	78.1	33.7	1.5	1.5	4.5	100.0%	17.2			
26/11	79.1	34.4	0.0	0.0	4.5	100.0%	21.7	5	20.0	0.0
30/11	83.0	37.1	3.3	3.3	4.7	100.0%	16.9			
1/12	84.0	37.8	0.0	0.0	4.7	100.0%	21.6	5	20.0	0.0
5/12	84.0	37.8	4.6	4.6	4.7	100.0%	15.7			
6/12	84.0	37.8	0.0	0.0	4.7	100.0%	20.4	5	20.0	0.0
10/12	84.0	37.8	5.4	5.4	4.6	100.0%	13.6			
11/12	84.0	37.8	0.0	0.0	4.6	100.0%	18.3	5	20.0	1.7
15/12	84.0	37.8	5.7	5.7	4.6	100.0%	12.7			
16/12	84.0	37.8	0.0	0.0	4.6	100.0%	17.3	5	20.0	2.7
20/12	84.0	37.8	5.8	5.8	4.6	100.0%	12.5			
21/12	84.0	37.8	0.0	0.0	4.6	100.0%	17.1	5	20.0	2.9
25/12	84.0	37.8	5.7	5.7	4.6	100.0%	12.6			
26/12	84.0	37.8	0.0	0.0	4.6	100.0%	17.1	5	20.0	2.9
30/12	84.0	37.8	2.2	2.2	4.5	100.0%	16.0			
31/12	84.0	38.1	0.0	0.0	4.5	100.0%	20.5	5	20.0	0.0
1/1	84.0	38.4	4.9	0.5	4.6	100.0%	4.6			
5/1	84.0	39.5	0.0	0.0	4.5	100.0%	22.6	5	20.0	0.0
6/1	84.0	39.8	4.9	2.6	4.5	100.0%	4.5			
10/1	84.0	40.9	0.0	0.0	4.4	100.0%	22.2	5	20.0	0.0
11/1	84.0	41.2	4.9	2.2	4.4	100.0%	4.4			
Total			49.0	39.6	393.5	100.0%			380.0	34.9

Table F-3 Crop water requirements for tomato

```
*************************************************************************
                    Crop Water Requirements Report
*************************************************************************
- Crop  # 1             : TOMATO    - Planting date         : 29/10
- Calculation time step = 4 Day(s)  - Irrigation Efficiency = 45%
```

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS l/s/ha
29/10	18.90	100.00	0.60	11.34	0.00	0.00	11.34	0.73
2/11	18.75	100.00	0.60	11.25	0.00	0.00	11.25	0.72
6/11	18.62	100.00	0.60	11.17	0.00	0.00	11.17	0.72
10/11	18.48	100.00	0.60	11.09	0.00	0.00	11.09	0.71
14/11	18.35	100.00	0.60	11.01	0.00	0.00	11.01	0.71
18/11	18.23	100.00	0.60	10.94	0.00	0.00	10.94	0.70
22/11	18.11	100.00	0.60	10.87	0.12	0.12	10.74	0.69
26/11	18.00	100.00	0.61	10.98	1.39	1.32	9.66	0.62
30/11	17.89	100.00	0.66	11.84	2.56	2.42	9.42	0.61
4/12	17.79	100.00	0.72	12.75	3.43	3.23	9.52	0.61
8/12	17.69	100.00	0.77	13.65	4.03	3.80	9.85	0.63
12/12	17.60	100.00	0.83	14.55	4.41	4.16	10.39	0.67
16/12	17.51	100.00	0.88	15.44	4.62	4.35	11.09	0.71
20/12	17.43	100.00	0.94	16.33	4.67	4.41	11.92	0.77
24/12	17.36	100.00	0.99	17.22	4.61	4.36	12.86	0.83
28/12	17.30	100.00	1.05	18.11	4.47	4.23	13.87	0.89
1/1	17.67	100.00	1.10	19.47	3.93	3.74	15.73	1.01
5/1	17.89	100.00	1.15	20.51	3.91	3.73	16.78	1.08
9/1	18.12	100.00	1.15	20.84	3.93	3.75	17.09	1.10
13/1	18.36	100.00	1.15	21.11	3.98	3.80	17.31	1.11
17/1	18.60	100.00	1.15	21.39	4.07	3.88	17.50	1.13
21/1	18.84	100.00	1.15	21.66	4.20	4.00	17.67	1.14
25/1	19.08	100.00	1.15	21.95	4.36	4.14	17.80	1.14
29/1	19.33	100.00	1.15	22.23	4.56	4.31	17.91	1.15
2/2	19.57	100.00	1.15	22.51	4.78	4.51	18.00	1.16
6/2	19.81	100.00	1.15	22.79	5.01	4.72	18.07	1.16
10/2	20.06	100.00	1.15	23.06	5.26	4.93	18.13	1.17
14/2	20.29	100.00	1.15	23.34	5.51	5.15	18.18	1.17
18/2	20.53	100.00	1.15	23.54	5.75	5.36	18.18	1.17
22/2	20.75	100.00	1.11	23.02	5.97	5.55	17.47	1.12
26/2	20.98	100.00	1.06	22.29	6.16	5.71	16.57	1.07
2/3	21.19	100.00	1.02	21.53	6.30	5.83	15.69	1.01
6/3	21.40	100.00	0.97	20.74	6.38	5.91	14.84	0.95
10/3	21.61	100.00	0.92	19.93	6.40	5.92	14.01	0.90
14/3	21.80	100.00	0.88	19.09	6.33	5.87	13.23	0.85
18/3	21.99	100.00	0.83	18.23	6.19	5.74	12.49	0.80
22/3	5.52	100.00	0.80	4.42	1.51	1.40	3.02	0.78
Total	691.39			642.19	138.77	130.36	511.83	0.91

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

Table F-4 Irrigation scheduling for tomato

```
**************************************************************************
                          Irrigation Scheduling Report
**************************************************************************
Crop Data: TOMATO
- Application Timing:     Irrigate each 4days.
- Applications Depths:     Fixed depths of 15mm each.
- Start of Scheduling: 29/10
--------------------------------------------------------------------------
```

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
29/10	35.0	10.5	0.0	0.0	2.8	100.0%	11.6	0	15.0	3.4
2/11	41.0	12.5	0.0	0.0	2.8	100.0%	11.3	4	15.0	3.7
6/11	47.0	14.6	0.0	0.0	2.8	100.0%	11.2	4	15.0	3.8
10/11	53.0	16.8	0.0	0.0	2.8	100.0%	11.1	4	15.0	3.9
14/11	59.0	19.0	0.0	0.0	2.8	100.0%	11.1	4	15.0	3.9
18/11	65.0	21.4	0.0	0.0	2.7	100.0%	11.0	4	15.0	4.0
22/11	71.0	23.7	0.0	0.0	2.7	100.0%	10.9	4	15.0	4.1
25/11	75.5	25.6	1.5	1.5	2.7	100.0%	6.6			
26/11	77.0	26.2	0.0	0.0	2.7	100.0%	9.3	4	15.0	5.7
30/11	83.0	28.7	3.3	3.3	2.9	100.0%	7.8	4	15.0	7.2
4/12	84.0	29.5	0.0	0.0	3.1	100.0%	12.1	4	15.0	2.9
5/12	84.0	29.6	4.6	0.0	3.2	100.0%	3.2			
8/12	84.0	30.0	0.0	0.0	3.3	100.0%	13.0	4	15.0	2.0
10/12	84.0	30.2	5.4	3.4	3.4	100.0%	3.4			
12/12	84.0	30.5	0.0	0.0	3.6	100.0%	10.5	4	15.0	4.5
15/12	84.0	30.8	5.7	5.7	3.7	100.0%	5.3			
16/12	84.0	31.0	0.0	0.0	3.8	100.0%	9.0	4	15.0	6.0
20/12	84.0	31.4	5.8	5.8	4.0	100.0%	9.8	4	15.0	5.2
24/12	84.0	31.9	0.0	0.0	4.2	100.0%	16.6	4	15.0	0.0
25/12	84.0	32.0	5.7	1.6	4.3	100.0%	4.3			
28/12	84.0	32.4	0.0	0.0	4.4	100.0%	17.4	4	15.0	0.0
30/12	84.0	32.6	2.2	2.2	4.6	100.0%	9.3			
1/1	84.0	32.9	4.9	4.9	4.8	100.0%	13.7	4	15.0	1.3
5/1	84.0	33.4	0.0	0.0	5.1	100.0%	19.8	4	15.0	0.0
6/1	84.0	33.5	4.9	4.8	5.1	100.0%	5.1			
9/1	84.0	33.6	0.0	0.0	5.2	100.0%	20.6	4	15.0	0.0
11/1	84.0	33.6	4.9	4.9	5.2	100.0%	11.1			
13/1	84.0	33.6	0.0	0.0	5.3	100.0%	21.6	4	15.0	0.0
16/1	84.0	33.6	5.1	5.1	5.3	100.0%	17.4			
17/1	84.0	33.6	0.0	0.0	5.3	100.0%	22.7	4	15.0	0.0
21/1	84.0	33.6	5.3	5.3	5.4	100.0%	23.9	4	15.0	0.0
25/1	84.0	33.6	0.0	0.0	5.5	100.0%	30.6	4	15.0	0.0
26/1	84.0	33.6	5.5	5.5	5.5	100.0%	15.6			
29/1	84.0	33.6	0.0	0.0	5.5	100.0%	32.1	4	15.0	0.0
31/1	84.0	33.6	5.9	5.9	5.6	100.0%	22.4			
2/2	84.0	33.6	0.0	0.0	5.6	100.0%	33.5	4	15.0	0.0
5/2	84.0	33.6	6.2	6.2	5.7	100.0%	29.2			
6/2	84.0	33.6	0.0	0.0	5.7	100.0%	34.9	4	15.0	0.0
10/2	84.0	33.6	6.6	6.6	5.7	100.0%	36.1	4	15.0	0.0
14/2	84.0	33.6	0.0	0.0	5.3	97.6%	43.7	4	15.0	0.0
15/2	84.0	33.6	7.0	7.0	5.8	100.0%	27.5			
18/2	84.0	33.6	0.0	0.0	5.2	96.3%	44.4	4	15.0	0.0

20/2	84.0	33.6	7.4	7.4	5.9	100.0%	33.9			
22/2	84.0	34.2	0.0	0.0	5.2	94.4%	44.9	4	15.0	0.0
25/2	84.0	35.0	7.7	7.7	5.7	99.3%	39.3			
26/2	84.0	35.3	0.0	0.0	5.2	91.7%	44.5	4	15.0	0.0
2/3	84.0	36.4	7.9	7.9	5.3	96.9%	43.0	4	15.0	0.0
6/3	84.0	37.5	0.0	0.0	4.5	95.8%	48.5	4	15.0	0.0
7/3	84.0	37.8	8.0	8.0	5.2	100.0%	30.7			
10/3	84.0	38.6	0.0	0.0	4.8	98.3%	45.8	4	15.0	0.0
12/3	84.0	39.2	8.0	8.0	5.0	100.0%	32.8			
14/3	84.0	39.8	0.0	0.0	4.9	100.0%	42.5	4	15.0	0.0
17/3	84.0	40.6	7.8	7.8	4.7	100.0%	34.0			
18/3	84.0	40.9	0.0	0.0	4.6	100.0%	38.7	4	15.0	0.0
22/3	84.0	42.0	7.4	7.4	4.4	100.0%	34.3	4	15.0	0.0
Total			144.7	133.8	637.9	99.3%			555.0	61.4

Table F-5 Crop water requirements for maize

```
****************************************************************************
                         Crop Water Requirements Report
****************************************************************************
- Crop  # 1            : MAIZE  (Grain)
- Block #              : [All blocks]
- Planting date        : 3/10
- Calculation time step = 6 Day(s)
- Irrigation Efficiency = 45%
----------------------------------------------------------------------------
Date     ETo      Planted  Crop     CWR      Total    Effect.  Irr.     FWS
                    Area    Kc      (ETm)    Rain     Rain     Req.
      (mm/period) (%)               ---------- (mm/period) ---------- l/s/ha
----------------------------------------------------------------------------
3/10     29.78    100.00   0.30     8.93     0.00     0.00     8.93     0.38
9/10     29.42    100.00   0.30     8.83     0.00     0.00     8.83     0.38
15/10    29.07    100.00   0.30     8.72     0.00     0.00     8.72     0.37
21/10    28.73    100.00   0.30     8.62     0.00     0.00     8.62     0.37
27/10    28.40    100.00   0.36     10.11    0.00     0.00     10.11    0.43
2/11     28.08    100.00   0.49     13.79    0.00     0.00     13.79    0.59
8/11     27.77    100.00   0.63     17.39    0.00     0.00     17.39    0.75
14/11    27.48    100.00   0.76     20.92    0.00     0.00     20.92    0.90
20/11    27.21    100.00   0.90     24.38    0.12     0.12     24.26    1.04
26/11    26.95    100.00   1.03     27.79    2.54     2.42     25.38    1.09
2/12     26.72    100.00   1.16     31.06    4.83     4.56     26.50    1.14
8/12     26.50    100.00   1.20     31.80    6.20     5.85     25.95    1.11
14/12    26.30    100.00   1.20     31.56    6.86     6.47     25.09    1.08
20/12    26.12    100.00   1.20     31.35    6.99     6.60     24.75    1.06
26/12    25.97    100.00   1.20     31.16    6.76     6.40     24.76    1.06
1/1      26.59    100.00   1.20     31.90    5.88     5.61     26.29    1.13
7/1      27.10    100.00   1.20     32.51    5.88     5.62     26.90    1.15
13/1     27.62    100.00   1.18     32.50    6.00     5.73     26.77    1.15
19/1     28.17    100.00   1.05     29.52    6.25     5.95     23.57    1.01
25/1     28.72    100.00   0.91     26.08    6.61     6.27     19.80    0.85
31/1     29.27    100.00   0.77     22.48    7.08     6.68     15.80    0.68
6/2      29.81    100.00   0.63     18.73    7.61     7.15     11.57    0.50
12/2     15.11    100.00   0.52     7.91     4.02     3.76     4.14     0.36
----------------------------------------------------------------------------
Total    626.89                     508.05   83.63    79.19    428.86   0.82
----------------------------------------------------------------------------
* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.
****************************************************************************
```

Table F-6 Irrigation scheduling for maize

```
*****************************************************************************
                           Irrigation Scheduling Report
*****************************************************************************
* Crop Data: MAIZE  (Grain)
- Application Timing:     Irrigate each 6days.
- Applications Depths:     Fixed depths of 20mm each.
- Start of Scheduling: 3/10
```

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
3/10	42.0	21.0	0.0	0.0	1.5	100.0%	22.5	0	20.0	0.0
9/10	51.0	25.5	0.0	0.0	1.5	100.0%	11.4	6	20.0	8.6
15/10	60.1	30.0	0.0	0.0	1.5	100.0%	8.8	6	20.0	11.2
21/10	69.1	34.6	0.0	0.0	1.4	100.0%	8.7	6	20.0	11.3
27/10	78.2	39.1	0.0	0.0	1.4	100.0%	8.6	6	20.0	11.4
2/11	87.2	43.6	0.0	0.0	2.0	100.0%	10.7	6	20.0	9.3
8/11	96.3	48.1	0.0	0.0	2.7	100.0%	14.4	6	20.0	5.6
14/11	105.3	52.7	0.0	0.0	3.2	100.0%	18.0	6	20.0	2.0
20/11	114.4	57.2	0.0	0.0	3.8	100.0%	21.5	6	20.0	0.0
25/11	121.9	61.0	1.5	1.5	4.3	100.0%	20.5			
26/11	123.4	61.7	0.0	0.0	4.4	100.0%	24.9	6	20.0	0.0
30/11	129.4	64.7	3.3	3.3	4.8	100.0%	20.1			
2/12	132.5	66.2	0.0	0.0	5.0	100.0%	30.0	6	20.0	0.0
5/12	137.0	68.5	4.6	4.6	5.2	100.0%	20.8			
8/12	140.0	70.0	0.0	0.0	5.3	100.0%	36.8	6	20.0	0.0
10/12	140.0	70.0	5.4	5.4	5.3	100.0%	22.0			
14/12	140.0	70.0	0.0	0.0	5.3	100.0%	43.2	6	20.0	0.0
15/12	140.0	70.0	5.7	5.7	5.3	100.0%	22.7			
20/12	140.0	70.0	5.8	5.8	5.2	100.0%	43.1	6	20.0	0.0
25/12	140.0	70.0	5.7	5.7	5.2	100.0%	43.5			
26/12	140.0	70.0	0.0	0.0	5.2	100.0%	48.7	6	20.0	0.0
30/12	140.0	70.0	2.2	2.2	5.2	100.0%	47.3			
1/1	140.0	70.0	4.9	4.9	5.3	100.0%	52.9	6	20.0	0.0
6/1	140.0	70.0	4.9	4.9	5.4	100.0%	54.6			
7/1	140.0	70.0	0.0	0.0	5.4	100.0%	60.0	6	20.0	0.0
11/1	140.0	70.0	4.9	4.9	5.4	100.0%	56.7			
13/1	140.0	70.0	0.0	0.0	5.5	100.0%	67.6	6	20.0	0.0
16/1	140.0	71.4	5.1	5.1	5.4	100.0%	59.0			
19/1	140.0	75.6	0.0	0.0	5.2	100.0%	74.7	6	20.0	0.0
21/1	140.0	78.4	5.3	5.3	5.0	100.0%	59.5			
25/1	140.0	84.0	0.0	0.0	4.6	100.0%	78.4	6	20.0	0.0
26/1	140.0	85.4	5.5	5.5	4.5	100.0%	57.4			
31/1	140.0	92.4	5.9	5.9	4.0	100.0%	72.5	6	20.0	0.0
5/2	140.0	99.4	6.2	6.2	3.5	100.0%	64.8			
6/2	140.0	100.8	0.0	0.0	3.4	100.0%	68.1	6	20.0	0.0
10/2	140.0	106.4	6.6	6.6	3.0	100.0%	54.0			
12/2	140.0	109.2	0.0	0.0	2.7	100.0%	59.6	6	20.0	0.0
Total			83.6	83.6	508.0	100.0%			460.0	59.4

Table F-7 Crop water requirements for sweet pepper

****

Crop Water Requirements Report

****

- Crop # 1 : Sweet Peppers
- Block # : [All blocks]
- Planting date : 3/10
- Calculation time step = 5 Day(s)
- Irrigation Efficiency = 45%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS l/s/ha
3/10	24.84	100.00	0.60	14.91	0.00	0.00	14.91	0.77
8/10	24.59	100.00	0.60	14.76	0.00	0.00	14.76	0.76
13/10	24.35	100.00	0.60	14.61	0.00	0.00	14.61	0.75
18/10	24.11	100.00	0.60	14.46	0.00	0.00	14.46	0.74
23/10	23.87	100.00	0.60	14.32	0.00	0.00	14.32	0.74
28/10	23.64	100.00	0.60	14.18	0.00	0.00	14.18	0.73
2/11	23.42	100.00	0.63	14.84	0.00	0.00	14.84	0.76
7/11	23.21	100.00	0.69	16.01	0.00	0.00	16.01	0.82
12/11	23.00	100.00	0.75	17.16	0.00	0.00	17.16	0.88
17/11	22.81	100.00	0.80	18.30	0.00	0.00	18.30	0.94
22/11	22.62	100.00	0.86	19.42	0.34	0.33	19.09	0.98
27/11	22.44	100.00	0.91	20.54	2.32	2.20	18.33	0.94
2/12	22.28	100.00	0.97	21.64	3.91	3.69	17.95	0.92
7/12	22.13	100.00	1.03	22.73	4.95	4.67	18.07	0.93
12/12	21.98	100.00	1.05	23.08	5.56	5.24	17.85	0.92
17/12	21.85	100.00	1.05	22.95	5.81	5.48	17.46	0.90
22/12	21.74	100.00	1.05	22.82	5.80	5.48	17.34	0.89
27/12	21.63	100.00	1.05	22.71	5.61	5.31	17.40	0.89
1/1	22.12	100.00	1.05	23.23	4.91	4.68	18.55	0.95
6/1	22.47	100.00	1.05	23.59	4.89	4.67	18.93	0.97
11/1	22.83	100.00	1.05	23.98	4.95	4.72	19.26	0.99
16/1	23.21	100.00	1.05	24.37	5.07	4.84	19.53	1.00
21/1	23.59	100.00	1.03	24.23	5.27	5.02	19.22	0.99
26/1	23.97	100.00	0.99	23.73	5.54	5.25	18.47	0.95
31/1	24.35	100.00	0.95	23.19	5.86	5.54	17.65	0.91
5/2	24.73	100.00	0.91	22.63	6.23	5.86	16.77	0.86
Total	601.78			518.40	77.01	72.99	445.42	0.88

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

****

Table F-8 Irrigation scheduling for sweet pepper

```
***************************************************************************
                          Irrigation Scheduling Report
***************************************************************************
* Crop Data: Sweet Peppers
- Application Timing:     Irrigate each 5days.
- Applications Depths:    Fixed depths of 15mm each.
- Start of Scheduling:  10/10
---------------------------------------------------------------------------
```

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
10/10	35.0	7.0	0.0	0.0	2.8	93.8%	11.5	0	15.0	3.5
15/10	40.5	8.4	0.0	0.0	2.6	97.5%	14.3	5	15.0	0.7
20/10	46.0	9.9	0.0	0.0	2.8	99.0%	14.4	5	15.0	0.6
25/10	51.5	11.4	0.0	0.0	2.9	99.9%	14.4	5	15.0	0.6
30/10	57.0	13.0	0.0	0.0	2.8	100.0%	14.2	5	15.0	0.8
4/11	62.5	14.7	0.0	0.0	2.8	100.0%	14.1	5	15.0	0.9
9/11	68.0	16.5	0.0	0.0	2.8	100.0%	14.0	5	15.0	1.0
14/11	73.5	18.4	0.0	0.0	3.1	100.0%	14.9	5	15.0	0.1
19/11	79.0	20.3	0.0	0.0	3.3	100.0%	16.0	5	15.0	0.0
24/11	84.0	22.2	0.0	0.0	3.5	100.0%	18.2	5	15.0	0.0
25/11	84.0	22.3	1.5	1.5	3.6	100.0%	5.3			
29/11	84.0	22.8	0.0	0.0	3.8	100.0%	20.0	5	15.0	0.0
30/11	84.0	22.9	3.3	3.3	3.8	100.0%	5.5			
4/12	84.0	23.4	0.0	0.0	4.0	100.0%	21.1	5	15.0	0.0
5/12	84.0	23.5	4.6	4.6	4.0	100.0%	5.6			
9/12	84.0	24.0	0.0	0.0	4.2	100.0%	22.1	5	15.0	0.0
10/12	84.0	24.1	5.4	5.4	4.2	100.0%	6.0			
14/12	84.0	24.6	0.0	0.0	4.4	100.0%	23.4	5	15.0	0.0
15/12	84.0	24.7	5.7	5.7	4.5	100.0%	7.1			
19/12	84.0	25.2	0.0	0.0	4.6	100.0%	25.3	5	15.0	0.0
20/12	84.0	25.2	5.8	5.8	4.6	100.0%	9.1			
24/12	84.0	25.2	0.0	0.0	4.6	100.0%	27.4	5	15.0	0.0
25/12	84.0	25.2	5.7	5.7	4.6	100.0%	11.2			
29/12	84.0	25.2	0.0	0.0	4.5	100.0%	29.4	5	15.0	0.0
30/12	84.0	25.2	2.2	2.2	4.5	100.0%	16.8			
1/1	84.0	25.2	4.9	4.9	4.6	100.0%	21.0			
3/1	84.0	25.2	0.0	0.0	4.6	99.6%	30.3	5	15.0	0.0
6/1	84.0	25.2	4.9	4.9	4.7	100.0%	24.4			
8/1	84.0	25.2	0.0	0.0	4.4	96.7%	33.5	5	15.0	0.0
11/1	84.0	25.2	4.9	4.9	4.8	100.0%	27.8			
13/1	84.0	25.2	0.0	0.0	4.2	91.7%	36.6	5	15.0	0.0
16/1	84.0	25.2	5.1	5.1	4.8	98.8%	30.8			
18/1	84.0	25.2	0.0	0.0	4.0	86.7%	39.3	5	15.0	0.0
21/1	84.0	25.2	5.3	5.3	4.6	95.9%	33.1			
23/1	84.0	25.2	0.0	0.0	3.9	82.9%	41.3	5	15.0	0.0
26/1	84.0	25.2	5.5	5.5	4.6	93.2%	34.7			
28/1	84.0	26.0	0.0	0.0	3.9	80.8%	42.8	5	15.0	0.0
31/1	84.0	28.6	5.9	5.9	4.7	94.9%	36.0			
2/2	84.0	30.2	0.0	0.0	4.0	84.5%	44.3	5	15.0	0.0
5/2	84.0	32.8	6.2	6.2	4.8	98.5%	37.4			

7/2	84.0	34.4	0.0	0.0	4.1	88.7%	45.9	5	15.0	0.0
10/2	84.0	37.0	6.6	6.6	4.7	100.0%	38.5			
12/2	84.0	38.6	0.0	0.0	4.2	94.2%	47.4	5	15.0	0.0
15/2	84.0	41.2	7.0	7.0	4.6	100.0%	39.2			
Total			90.6	90.6	507.5	97.6%			390.0	8.2

Table F-9 Crop water requirements for mango

```
***************************************************************************
                        Crop Water Requirements Report
***************************************************************************
- Crop  # 1             : MANGO
- Block #               : [All blocks]
- Planting date         : 1/1
- Calculation time step = 8 Day(s)
- Irrigation Efficiency = 45%
---------------------------------------------------------------------------
```

Date	ETo	Planted Area	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS
	(mm/period)	(%)		(mm/period)	(mm/period)	(mm/period)	(mm/period)	l/s/ha
1/1	35.56	100.00	0.90	32.00	7.84	7.47	24.53	0.79
9/1	36.48	100.00	0.90	32.83	7.91	7.55	25.28	0.81
17/1	37.43	100.00	0.90	33.69	8.27	7.88	25.81	0.83
25/1	38.41	100.00	0.90	34.57	8.92	8.45	26.12	0.84
2/2	39.39	100.00	0.90	35.45	9.79	9.22	26.23	0.84
10/2	40.35	100.00	0.90	36.31	10.78	10.09	26.23	0.84
18/2	41.28	100.00	0.90	37.15	11.72	10.91	26.24	0.84
26/2	42.17	100.00	0.90	37.95	12.45	11.55	26.41	0.85
6/3	43.01	100.00	0.90	38.71	12.77	11.83	26.88	0.86
14/3	43.79	100.00	0.90	39.41	12.52	11.60	27.81	0.89
22/3	44.49	100.00	0.90	40.04	11.57	10.76	29.28	0.94
30/3	45.13	100.00	0.91	40.88	9.89	9.27	31.61	1.02
7/4	45.68	100.00	0.92	42.18	7.56	7.19	34.99	1.12
15/4	46.15	100.00	0.94	43.43	4.87	4.74	38.69	1.24
23/4	46.53	100.00	0.96	44.62	2.29	2.28	42.33	1.36
1/5	46.83	100.00	0.98	45.74	0.48	0.47	45.26	1.46
9/5	47.04	100.00	0.99	46.78	0.00	0.00	46.78	1.50
17/5	47.16	100.00	1.01	47.73	0.00	0.00	47.73	1.53
25/5	47.19	100.00	1.03	48.61	7.61	5.39	43.22	1.39
2/6	47.15	100.00	1.05	49.40	20.10	15.22	34.18	1.10
10/6	47.02	100.00	1.07	50.11	22.09	18.73	31.38	1.01
18/6	46.82	100.00	1.08	50.72	20.46	19.40	31.33	1.01
26/6	46.55	100.00	1.10	51.13	19.90	19.73	31.40	1.01
4/7	46.21	100.00	1.10	50.83	22.81	21.13	29.70	0.95
12/7	45.81	100.00	1.10	50.39	29.64	24.05	26.34	0.85
20/7	45.36	100.00	1.10	49.89	39.32	28.19	21.70	0.70
28/7	44.85	100.00	1.10	49.34	49.76	32.72	16.62	0.53
5/8	44.31	100.00	1.10	48.74	58.27	36.46	12.27	0.39
13/8	43.73	100.00	1.10	48.10	62.17	38.19	9.91	0.32
21/8	43.12	100.00	1.10	47.43	59.39	36.85	10.57	0.34
29/8	42.48	100.00	1.10	46.73	49.07	31.91	14.82	0.48
6/9	41.84	100.00	1.10	46.02	32.27	23.60	22.42	0.72
14/9	41.18	100.00	1.10	45.30	12.73	11.93	33.36	1.07
22/9	40.52	100.00	1.10	44.54	0.43	0.43	44.11	1.42
30/9	39.87	100.00	1.09	43.31	0.00	0.00	43.31	1.39
8/10	39.23	100.00	1.07	41.96	0.00	0.00	41.96	1.35
16/10	38.61	100.00	1.05	40.64	0.00	0.00	40.64	1.31
24/10	38.01	100.00	1.04	39.37	0.00	0.00	39.37	1.27
1/11	37.44	100.00	1.02	38.15	0.00	0.00	38.15	1.23
9/11	36.90	100.00	1.00	36.98	0.00	0.00	36.98	1.19

17/11	36.40	100.00	0.99	35.86	0.00	0.00	35.86	1.15
25/11	35.94	100.00	0.97	34.80	3.33	3.18	31.63	1.02
3/12	35.52	100.00	0.95	33.80	7.14	6.73	27.07	0.87
11/12	35.15	100.00	0.93	32.86	8.92	8.41	24.45	0.79
19/12	34.83	100.00	0.92	31.97	9.30	8.79	23.19	0.75
27/12	21.63	100.00	0.90	19.56	5.61	5.31	14.25	0.73
Total	1910.55			1916.03	679.93	527.62	1388.40	0.98

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

****

Table F-10 Irrigation scheduling for mango

```
****************************************************************************
                          Irrigation Scheduling Report
****************************************************************************
* Crop Data: MANGO
- Application Timing:     Irrigate each 8days.
- Applications Depths:    Fixed depths of 35mm each.
- Start of Scheduling: 1/1
----------------------------------------------------------------------------
```

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
1/1	280.0	168.0	4.9	4.9	4.0	100.0%	139.1	0	35.0	0.0
6/1	280.0	168.0	4.9	4.9	4.0	100.0%	119.1			
9/1	280.0	168.0	0.0	0.0	4.1	100.0%	131.3	8	35.0	0.0
11/1	280.0	168.0	4.9	4.9	4.1	100.0%	99.5			
16/1	280.0	168.0	5.1	5.1	4.2	100.0%	115.0			
17/1	280.0	168.0	0.0	0.0	4.2	100.0%	119.2	8	35.0	0.0
21/1	280.0	168.0	5.3	5.3	4.2	100.0%	95.7			
25/1	280.0	168.0	0.0	0.0	4.3	100.0%	112.7	8	35.0	0.0
26/1	280.0	168.0	5.5	5.5	4.3	100.0%	76.5			
31/1	280.0	168.0	5.9	5.9	4.4	100.0%	92.2			
2/2	280.0	168.0	0.0	0.0	4.4	100.0%	101.0	8	35.0	0.0
5/2	280.0	168.0	6.2	6.2	4.4	100.0%	73.0			
10/2	280.0	168.0	6.6	6.6	4.5	100.0%	88.7	8	35.0	0.0
15/2	280.0	168.0	7.0	7.0	4.6	100.0%	69.4			
18/2	280.0	168.0	0.0	0.0	4.6	100.0%	83.1	8	35.0	0.0
20/2	280.0	168.0	7.4	7.4	4.6	100.0%	50.0			
25/2	280.0	168.0	7.7	7.7	4.7	100.0%	65.6			
26/2	280.0	168.0	0.0	0.0	4.7	100.0%	70.3	8	35.0	0.0
2/3	280.0	168.0	7.9	7.9	4.8	100.0%	46.4			
6/3	280.0	168.0	0.0	0.0	4.8	100.0%	65.5	8	35.0	0.0
7/3	280.0	168.0	8.0	8.0	4.8	100.0%	27.3			
12/3	280.0	168.0	8.0	8.0	4.9	100.0%	43.6			
14/3	280.0	168.0	0.0	0.0	4.9	100.0%	53.4	8	35.0	0.0
17/3	280.0	168.0	7.8	7.8	4.9	100.0%	25.3			
22/3	280.0	168.0	7.4	7.4	5.0	100.0%	42.7	8	35.0	0.0
27/3	280.0	168.0	6.8	6.8	5.0	100.0%	25.9			
30/3	280.0	168.0	0.0	0.0	5.0	100.0%	41.0	8	35.0	0.0
1/4	280.0	168.0	6.1	6.1	5.1	100.0%	10.0			
6/4	280.0	168.0	5.2	5.2	5.2	100.0%	30.5			
7/4	280.0	168.0	0.0	0.0	5.2	100.0%	35.7	8	35.0	0.0
11/4	280.0	168.0	4.2	4.2	5.3	100.0%	17.5			
15/4	280.0	168.0	0.0	0.0	5.4	100.0%	38.8	8	35.0	0.0
16/4	280.0	168.0	3.1	3.1	5.4	100.0%	6.0			
21/4	280.0	168.0	2.1	2.1	5.5	100.0%	31.1			
23/4	280.0	168.0	0.0	0.0	5.5	100.0%	42.1	8	35.0	0.0
26/4	280.0	168.0	1.2	1.2	5.6	100.0%	22.6			
1/5	280.0	168.0	0.5	0.5	5.7	100.0%	50.3	8	35.0	0.0
9/5	280.0	168.0	0.0	0.0	5.8	100.0%	61.1	8	35.0	0.0
17/5	280.0	168.0	0.0	0.0	5.9	100.0%	73.0	8	35.0	0.0
25/5	280.0	168.0	0.0	0.0	6.0	100.0%	85.9	8	35.0	0.0
26/5	280.0	168.0	4.0	4.0	6.0	100.0%	53.0			
31/5	280.0	168.0	10.4	10.4	6.1	100.0%	72.9			

2/6	280.0	168.0	0.0	0.0	6.1	100.0%	85.2	8	35.0	0.0
5/6	280.0	168.0	13.3	13.3	6.2	100.0%	55.4			
10/6	280.0	168.0	13.9	13.9	6.2	100.0%	72.5	8	35.0	0.0
15/6	280.0	168.0	13.4	13.4	6.3	100.0%	55.3			
18/6	280.0	168.0	0.0	0.0	6.3	100.0%	74.2	8	35.0	0.0
20/6	280.0	168.0	12.7	12.7	6.3	100.0%	39.1			
25/6	280.0	168.0	12.3	12.3	6.4	100.0%	58.6			
26/6	280.0	168.0	0.0	0.0	6.4	100.0%	65.0	8	35.0	0.0
30/6	280.0	168.0	12.7	12.7	6.4	100.0%	42.9			
4/7	280.0	168.0	0.0	0.0	6.4	100.0%	68.4	8	35.0	0.0
5/7	280.0	168.0	14.0	14.0	6.4	100.0%	25.8			
10/7	280.0	168.0	16.3	16.3	6.3	100.0%	41.2			
12/7	280.0	168.0	0.0	0.0	6.3	100.0%	53.9	8	35.0	0.0
15/7	280.0	168.0	19.5	19.5	6.3	100.0%	18.3			
20/7	280.0	168.0	23.3	23.3	6.3	100.0%	26.4	8	35.0	8.6
25/7	280.0	168.0	27.5	25.0	6.2	100.0%	6.2			
28/7	280.0	168.0	0.0	0.0	6.2	100.0%	24.8	8	35.0	10.2
30/7	280.0	168.0	31.5	6.2	6.2	100.0%	6.2			
4/8	280.0	168.0	35.1	30.8	6.1	100.0%	6.1			
5/8	280.0	168.0	0.0	0.0	6.1	100.0%	12.3	8	35.0	22.7
9/8	280.0	168.0	37.6	18.3	6.1	100.0%	6.1			
13/8	280.0	168.0	0.0	0.0	6.0	100.0%	30.3	8	35.0	4.7
14/8	280.0	168.0	38.9	0.0	6.0	100.0%	6.0			
19/8	280.0	168.0	38.6	30.1	6.0	100.0%	6.0			
21/8	280.0	168.0	0.0	0.0	6.0	100.0%	17.9	8	35.0	17.1
24/8	280.0	168.0	36.4	11.9	5.9	100.0%	5.9			
29/8	280.0	168.0	32.3	29.6	5.9	100.0%	5.9	8	35.0	29.1
3/9	280.0	168.0	26.6	23.4	5.8	100.0%	5.8			
6/9	280.0	168.0	0.0	0.0	5.8	100.0%	23.2	8	35.0	11.8
8/9	280.0	168.0	19.5	5.8	5.8	100.0%	5.8			
13/9	280.0	168.0	11.7	11.7	5.7	100.0%	22.7			
14/9	280.0	168.0	0.0	0.0	5.7	100.0%	28.4	8	35.0	6.6
18/9	280.0	168.0	4.3	4.3	5.7	100.0%	18.4			
22/9	280.0	168.0	0.0	0.0	5.6	100.0%	40.9	8	35.0	0.0
23/9	280.0	168.0	0.1	0.1	5.6	100.0%	11.4			
30/9	280.0	168.0	0.0	0.0	5.5	100.0%	50.2	8	35.0	0.0
8/10	280.0	168.0	0.0	0.0	5.3	100.0%	58.4	8	35.0	0.0
16/10	280.0	168.0	0.0	0.0	5.2	100.0%	65.2	8	35.0	0.0
24/10	280.0	168.0	0.0	0.0	5.0	100.0%	70.6	8	35.0	0.0
1/11	280.0	168.0	0.0	0.0	4.8	100.0%	74.8	8	35.0	0.0
9/11	280.0	168.0	0.0	0.0	4.7	100.0%	77.8	8	35.0	0.0
17/11	280.0	168.0	0.0	0.0	4.5	100.0%	79.7	8	35.0	0.0
25/11	280.0	168.0	1.5	1.5	4.4	100.0%	78.9	8	35.0	0.0
30/11	280.0	168.0	3.3	3.3	4.3	100.0%	62.3			
3/12	280.0	168.0	0.0	0.0	4.3	100.0%	75.2	8	35.0	0.0
5/12	280.0	168.0	4.6	4.6	4.2	100.0%	44.2			
10/12	280.0	168.0	5.4	5.4	4.2	100.0%	59.8			
11/12	280.0	168.0	0.0	0.0	4.2	100.0%	64.0	8	35.0	0.0
15/12	280.0	168.0	5.7	5.7	4.1	100.0%	39.7			
19/12	280.0	168.0	0.0	0.0	4.0	100.0%	56.0	8	35.0	0.0
20/12	280.0	168.0	5.8	5.8	4.0	100.0%	19.2			
25/12	280.0	168.0	5.7	5.7	4.0	100.0%	33.4			
27/12	280.0	168.0	0.0	0.0	3.9	100.0%	41.3	8	35.0	0.0
30/12	280.0	168.0	2.2	2.2	3.9	100.0%	15.8			
Total			679.9	537.0	1916.0	100.0%			1610.0	110.7

Table F-11 Crop water requirements for sugarcane

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Crop Water Requirements Report

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- Crop # 1 : Sugarcane
- Planting date : 1/1
- Calculation time step = 8 Day(s)
- Irrigation Efficiency = 45%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS l/s/ha
1/1	35.56	100.00	0.40	14.22	7.84	7.47	6.75	0.22
9/1	36.48	100.00	0.40	14.59	7.91	7.55	7.04	0.23
17/1	37.43	100.00	0.40	14.97	8.27	7.88	7.10	0.23
25/1	38.41	100.00	0.41	15.57	8.92	8.45	7.12	0.23
2/2	39.39	100.00	0.49	19.39	9.79	9.22	10.17	0.33
10/2	40.35	100.00	0.61	24.44	10.78	10.09	14.35	0.46
18/2	41.28	100.00	0.72	29.68	11.72	10.91	18.77	0.60
26/2	42.17	100.00	0.83	35.10	12.45	11.55	23.55	0.76
6/3	43.01	100.00	0.95	40.67	12.77	11.83	28.84	0.93
14/3	43.79	100.00	1.06	46.37	12.52	11.60	34.76	1.12
22/3	44.49	100.00	1.17	52.16	11.57	10.76	41.40	1.33
30/3	45.13	100.00	1.25	56.33	9.89	9.27	47.06	1.51
7/4	45.68	100.00	1.25	57.10	7.56	7.19	49.91	1.60
15/4	46.15	100.00	1.25	57.69	4.87	4.74	52.94	1.70
23/4	46.53	100.00	1.25	58.17	2.29	2.28	55.88	1.80
1/5	46.83	100.00	1.25	58.54	0.48	0.47	58.06	1.87
9/5	47.04	100.00	1.25	58.80	0.00	0.00	58.80	1.89
17/5	47.16	100.00	1.25	58.95	0.00	0.00	58.95	1.90
25/5	47.19	100.00	1.25	58.99	7.61	5.39	53.61	1.72
2/6	47.15	100.00	1.25	58.94	20.10	15.22	43.71	1.41
10/6	47.02	100.00	1.25	58.78	22.09	18.73	40.05	1.29
18/6	46.82	100.00	1.25	58.53	20.46	19.40	39.13	1.26
26/6	46.55	100.00	1.25	58.19	19.90	19.73	38.46	1.24
4/7	46.21	100.00	1.25	57.76	22.81	21.13	36.64	1.18
12/7	45.81	100.00	1.25	57.26	29.64	24.05	33.22	1.07
20/7	45.36	100.00	1.25	56.69	39.32	28.19	28.50	0.92
28/7	44.85	100.00	1.25	56.07	49.76	32.72	23.35	0.75
5/8	44.31	100.00	1.25	55.38	58.27	36.46	18.92	0.61
13/8	43.73	100.00	1.25	54.66	62.17	38.19	16.47	0.53
21/8	43.12	100.00	1.25	53.89	59.39	36.85	17.04	0.55
29/8	42.48	100.00	1.25	53.10	49.07	31.91	21.20	0.68
6/9	41.84	100.00	1.25	52.30	32.27	23.60	28.70	0.92
14/9	41.18	100.00	1.25	51.48	12.73	11.93	39.54	1.27
22/9	40.52	100.00	1.25	50.58	0.43	0.43	50.14	1.61
30/9	39.87	100.00	1.22	48.48	0.00	0.00	48.48	1.56
8/10	39.23	100.00	1.17	46.05	0.00	0.00	46.05	1.48
16/10	38.61	100.00	1.13	43.69	0.00	0.00	43.69	1.40
24/10	38.01	100.00	1.09	41.41	0.00	0.00	41.41	1.33
1/11	37.44	100.00	1.05	39.21	0.00	0.00	39.21	1.26
9/11	36.90	100.00	1.01	37.10	0.00	0.00	37.10	1.19
17/11	36.40	100.00	0.96	35.06	0.00	0.00	35.06	1.13
25/11	35.94	100.00	0.92	33.10	3.33	3.18	29.93	0.96

3/12	35.52	100.00	0.88	31.22	7.14	6.73	24.50	0.79
11/12	35.15	100.00	0.84	29.42	8.92	8.41	21.01	0.68
19/12	34.83	100.00	0.79	27.68	9.30	8.79	18.90	0.61
27/12	21.63	100.00	0.76	16.45	5.61	5.31	11.14	0.57
Total	1910.55			2034.19	679.93	527.62	1506.56	1.06

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ETo data is distributed using polynomial curve fitting.

* Rainfall data is distributed using polynomial curve fitting.

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Table F-12 Irrigation scheduling for sugarcane

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                         Irrigation Scheduling Report
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* Crop Data: Sugarcane
- Application Timing:      Irrigate each 8days.
- Applications Depths:     Fixed depths of 35mm each.
- Start of Scheduling: 1/1
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Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
1/1	210.0	126.0	4.9	0.0	1.8	100.0%	1.8			
6/1	210.0	126.0	4.9	4.9	1.8	100.0%	5.7			
9/1	210.0	126.0	0.0	0.0	1.8	100.0%	11.1	8	35.0	23.9
11/1	210.0	126.0	4.9	1.8	1.8	100.0%	1.8			
16/1	210.0	126.0	5.1	5.1	1.8	100.0%	5.9			
17/1	210.0	126.0	0.0	0.0	1.9	100.0%	7.8	8	35.0	27.2
21/1	210.0	126.0	5.3	5.3	1.9	100.0%	2.2			
25/1	210.0	126.0	0.0	0.0	1.9	100.0%	9.8	8	35.0	25.2
26/1	210.0	126.0	5.5	0.0	1.9	100.0%	1.9			
31/1	210.0	126.0	5.9	5.9	2.0	100.0%	5.7			
2/2	210.0	126.0	0.0	0.0	2.2	100.0%	10.0	8	35.0	25.0
5/2	210.0	126.0	6.2	4.5	2.4	100.0%	2.4			
10/2	210.0	126.0	6.6	6.6	2.8	100.0%	8.9	8	35.0	26.1
15/2	210.0	126.0	7.0	7.0	3.2	100.0%	8.1			
18/2	210.0	126.0	0.0	0.0	3.4	100.0%	18.1	8	35.0	16.9
20/2	210.0	126.0	7.4	3.5	3.6	100.0%	3.6			
25/2	210.0	126.0	7.7	7.7	4.0	100.0%	15.1			
26/2	210.0	126.0	0.0	0.0	4.1	100.0%	19.2	8	35.0	15.8
2/3	210.0	126.0	7.9	7.9	4.4	100.0%	9.3			
6/3	210.0	126.0	0.0	0.0	4.8	100.0%	27.9	8	35.0	7.1
7/3	210.0	126.0	8.0	0.0	4.9	100.0%	4.9			
12/3	210.0	126.0	8.0	8.0	5.3	100.0%	22.5			
14/3	210.0	126.0	0.0	0.0	5.5	100.0%	33.4	8	35.0	1.6
17/3	210.0	126.0	7.8	7.8	5.8	100.0%	9.2			
22/3	210.0	126.0	7.4	7.4	6.2	100.0%	31.9	8	35.0	3.1
27/3	210.0	126.0	6.8	6.8	6.7	100.0%	25.5			
30/3	210.0	126.0	0.0	0.0	6.9	100.0%	46.0	8	35.0	0.0
1/4	210.0	126.0	6.1	6.1	7.0	100.0%	19.0			
6/4	210.0	126.0	5.2	5.2	7.1	100.0%	49.1			
7/4	210.0	126.0	0.0	0.0	7.1	100.0%	56.2	8	35.0	0.0
11/4	210.0	126.0	4.2	4.2	7.1	100.0%	45.5			
15/4	210.0	126.0	0.0	0.0	7.2	100.0%	74.2	8	35.0	0.0
16/4	210.0	126.0	3.1	3.1	7.2	100.0%	43.2			
21/4	210.0	126.0	2.1	2.1	7.2	100.0%	77.2			
23/4	210.0	126.0	0.0	0.0	7.2	100.0%	91.7	8	35.0	0.0
26/4	210.0	126.0	1.2	1.2	7.3	100.0%	77.3			
1/5	210.0	126.0	0.5	0.5	7.3	100.0%	113.3	8	35.0	0.0
9/5	210.0	126.0	0.0	0.0	7.0	99.5%	136.5	8	35.0	0.0
17/5	210.0	126.0	0.0	0.0	5.3	91.2%	155.2	8	35.0	0.0
25/5	210.0	126.0	0.0	0.0	4.2	78.8%	166.7	8	35.0	0.0
26/5	210.0	126.0	4.0	4.0	7.2	98.0%	134.9			
31/5	210.0	126.0	10.4	10.4	5.5	77.5%	153.0			

2/6	210.0	126.0	0.0	0.0	4.6	64.8%	162.6	8	35.0	0.0
5/6	210.0	126.0	13.3	13.3	7.2	95.0%	135.3			
10/6	210.0	126.0	13.9	13.9	5.8	77.9%	150.1	8	35.0	0.0
15/6	210.0	126.0	13.4	13.4	7.0	95.6%	136.8			
18/6	210.0	126.0	0.0	0.0	5.3	79.8%	154.3	8	35.0	0.0
20/6	210.0	126.0	12.7	12.7	7.3	100.0%	121.3			
25/6	210.0	126.0	12.3	12.3	6.5	90.9%	142.2			
26/6	210.0	126.0	0.0	0.0	5.9	80.7%	148.1	8	35.0	0.0
30/6	210.0	126.0	12.7	12.7	7.3	99.5%	129.4			
4/7	210.0	126.0	0.0	0.0	5.3	84.2%	153.8	8	35.0	0.0
5/7	210.0	126.0	14.0	14.0	7.2	100.0%	112.1			
10/7	210.0	126.0	16.3	16.3	7.2	98.0%	131.1			
12/7	210.0	126.0	0.0	0.0	6.2	89.9%	144.1	8	35.0	0.0
15/7	210.0	126.0	19.5	19.5	7.2	100.0%	111.1			
20/7	210.0	126.0	23.3	23.3	7.1	98.5%	122.8	8	35.0	0.0
25/7	210.0	126.0	27.5	27.5	7.1	100.0%	95.8			
28/7	210.0	126.0	0.0	0.0	7.0	100.0%	117.0	8	35.0	0.0
30/7	210.0	126.0	31.5	31.5	7.0	100.0%	64.5			
4/8	210.0	126.0	35.1	35.1	7.0	100.0%	64.4			
5/8	210.0	126.0	0.0	0.0	7.0	100.0%	71.4	8	35.0	0.0
9/8	210.0	126.0	37.6	37.6	6.9	100.0%	26.5			
13/8	210.0	126.0	0.0	0.0	6.9	100.0%	54.0	8	35.0	0.0
14/8	210.0	126.0	38.9	19.0	6.9	100.0%	6.9			
19/8	210.0	126.0	38.6	34.2	6.8	100.0%	6.8			
21/8	210.0	126.0	0.0	0.0	6.8	100.0%	20.4	8	35.0	14.6
24/8	210.0	126.0	36.4	13.5	6.7	100.0%	6.7			
29/8	210.0	126.0	32.3	32.3	6.7	100.0%	7.9	8	35.0	27.1
3/9	210.0	126.0	26.6	26.6	6.6	100.0%	6.7			
6/9	210.0	126.0	0.0	0.0	6.6	100.0%	26.4	8	35.0	8.6
8/9	210.0	126.0	19.5	6.6	6.6	100.0%	6.6			
13/9	210.0	126.0	11.7	11.7	6.5	100.0%	27.4			
14/9	210.0	126.0	0.0	0.0	6.5	100.0%	33.9	8	35.0	1.1
18/9	210.0	126.0	4.3	4.3	6.4	100.0%	21.5			
22/9	210.0	126.0	0.0	0.0	6.4	100.0%	47.1	8	35.0	0.0
23/9	210.0	126.0	0.1	0.1	6.4	100.0%	18.3			
30/9	210.0	126.0	0.0	0.0	6.2	100.0%	62.4	8	35.0	0.0
8/10	210.0	126.0	0.0	0.0	5.9	100.0%	75.5	8	35.0	0.0
16/10	210.0	126.0	0.0	0.0	5.6	100.0%	86.3	8	35.0	0.0
24/10	210.0	126.0	0.0	0.0	5.3	100.0%	94.7	8	35.0	0.0
1/11	210.0	126.0	0.0	0.0	5.0	100.0%	100.8	8	35.0	0.0
9/11	210.0	126.0	0.0	0.0	4.8	100.0%	104.8	8	35.0	0.0
17/11	210.0	126.0	0.0	0.0	4.5	100.0%	106.6	8	35.0	0.0
25/11	210.0	126.0	1.5	1.5	4.2	100.0%	104.9	8	35.0	0.0
30/11	210.0	126.0	3.3	3.3	4.1	100.0%	87.3			
3/12	210.0	126.0	0.0	0.0	4.0	100.0%	99.4	8	35.0	0.0
5/12	210.0	126.0	4.6	4.6	3.9	100.0%	67.7			
10/12	210.0	126.0	5.4	5.4	3.8	100.0%	81.7			
11/12	210.0	126.0	0.0	0.0	3.8	100.0%	85.4	8	35.0	0.0
15/12	210.0	126.0	5.7	5.7	3.7	100.0%	59.5			
19/12	210.0	126.0	0.0	0.0	3.6	100.0%	73.9	8	35.0	0.0
20/12	210.0	126.0	5.8	5.8	3.5	100.0%	36.6			
25/12	210.0	126.0	5.7	5.7	3.4	100.0%	48.1			
27/12	210.0	126.0	0.0	0.0	3.3	100.0%	54.8	8	35.0	0.0
30/12	210.0	126.0	2.2	2.2	3.3	100.0%	27.5			
Total			679.9	592.8	1975.297.1%				1575.0	223.4

Table F-13 Crop water requirements for citrus (orange)

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                    Crop Water Requirements Report
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- Crop  # 1             : CITRUS (70% cover, cool season 15 Nov.)
- Block #               : [All blocks]
- Planting date         : 1/1
- Calculation time step = 8 Day(s)
- Irrigation Efficiency = 45%
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Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS l/s/ha
1/1	35.56	100.00	0.70	24.89	7.84	7.47	17.42	0.56
9/1	36.48	100.00	0.70	25.53	7.91	7.55	17.99	0.58
17/1	37.43	100.00	0.70	26.20	8.27	7.88	18.33	0.59
25/1	38.41	100.00	0.70	26.89	8.92	8.45	18.43	0.59
2/2	39.39	100.00	0.70	27.57	9.79	9.22	18.35	0.59
10/2	40.35	100.00	0.70	28.24	10.78	10.09	18.16	0.58
18/2	41.28	100.00	0.70	28.90	11.72	10.91	17.98	0.58
26/2	42.17	100.00	0.70	29.52	12.45	11.55	17.97	0.58
6/3	43.01	100.00	0.70	30.11	12.77	11.83	18.28	0.59
14/3	43.79	100.00	0.70	30.65	12.52	11.60	19.05	0.61
22/3	44.49	100.00	0.70	31.15	11.57	10.76	20.39	0.66
30/3	45.13	100.00	0.70	31.59	9.89	9.27	22.32	0.72
7/4	45.68	100.00	0.70	31.98	7.56	7.19	24.78	0.80
15/4	46.15	100.00	0.70	32.30	4.87	4.74	27.56	0.89
23/4	46.53	100.00	0.70	32.57	2.29	2.28	30.29	0.97
1/5	46.83	100.00	0.70	32.78	0.48	0.47	32.31	1.04
9/5	47.04	100.00	0.70	32.93	0.00	0.00	32.93	1.06
17/5	47.16	100.00	0.70	33.01	0.00	0.00	33.01	1.06
25/5	47.19	100.00	0.70	33.03	7.61	5.39	27.64	0.89
2/6	47.15	100.00	0.70	32.83	20.10	15.22	17.61	0.57
10/6	47.02	100.00	0.69	32.54	22.09	18.73	13.81	0.44
18/6	46.82	100.00	0.69	32.19	20.46	19.40	12.79	0.41
26/6	46.55	100.00	0.68	31.80	19.90	19.73	12.07	0.39
4/7	46.21	100.00	0.68	31.36	22.81	21.13	10.23	0.33
12/7	45.81	100.00	0.67	30.88	29.64	24.05	6.84	0.22
20/7	45.36	100.00	0.67	30.38	39.32	28.19	2.18	0.07
28/7	44.85	100.00	0.67	29.84	49.76	32.72	0.00	0.00
5/8	44.31	100.00	0.66	29.28	58.27	36.46	0.00	0.00
13/8	43.73	100.00	0.66	28.70	62.17	38.19	0.00	0.00
21/8	43.12	100.00	0.65	28.11	59.39	36.85	0.00	0.00
29/8	42.48	100.00	0.65	27.61	49.07	31.91	0.00	0.00
6/9	41.84	100.00	0.65	27.19	32.27	23.60	3.59	0.12
14/9	41.18	100.00	0.65	26.77	12.73	11.93	14.83	0.48
22/9	40.52	100.00	0.65	26.34	0.43	0.43	25.91	0.83
30/9	39.87	100.00	0.65	25.92	0.00	0.00	25.92	0.83
8/10	39.23	100.00	0.65	25.50	0.00	0.00	25.50	0.82
16/10	38.61	100.00	0.65	25.10	0.00	0.00	25.10	0.81
24/10	38.01	100.00	0.65	24.71	0.00	0.00	24.71	0.79
1/11	37.44	100.00	0.65	24.33	0.00	0.00	24.33	0.78
9/11	36.90	100.00	0.65	23.98	0.00	0.00	23.98	0.77

17/11	36.40	100.00	0.65	23.66	0.00	0.00	23.66	0.76
25/11	35.94	100.00	0.65	23.49	3.33	3.18	20.32	0.65
3/12	35.52	100.00	0.66	23.62	7.14	6.73	16.89	0.54
11/12	35.15	100.00	0.68	23.78	8.92	8.41	15.37	0.49
19/12	34.83	100.00	0.69	23.96	9.30	8.79	15.17	0.49
27/12	21.63	100.00	0.70	15.08	5.61	5.31	9.77	0.50
Total	1910.55			1298.79	679.93	527.62	803.76	0.57

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Table F-14 Irrigation scheduling for citrus (orange)

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Irrigation Scheduling Report

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* Crop Data: CITRUS (70% cover, cool season 15 Nov.)
- Application Timing: Irrigate each 8days.
- Applications Depths: Fixed depths of 20mm each.
- Start of Scheduling: 1/1

Date	TAM (mm)	RAM (mm)	Total Rain (mm)	Efct. Rain (mm)	ETc (mm)	ETc/ETm (%)	SMD (mm)	Interv. (Days)	Net Irr. (mm)	Lost Irr. (mm)
1/1	196.0	98.0	4.9	0.0	3.1	100.0%	3.1			
6/1	196.0	98.0	4.9	4.9	3.1	100.0%	13.7			
9/1	196.0	98.0	0.0	0.0	3.2	100.0%	23.2	8	20.0	0.0
11/1	196.0	98.0	4.9	4.9	3.2	100.0%	4.6			
16/1	196.0	98.0	5.1	5.1	3.2	100.0%	15.5			
17/1	196.0	98.0	0.0	0.0	3.2	100.0%	18.8	8	20.0	1.2
21/1	196.0	98.0	5.3	5.3	3.3	100.0%	7.8			
25/1	196.0	98.0	0.0	0.0	3.3	100.0%	21.0	8	20.0	0.0
26/1	196.0	98.0	5.5	1.0	3.3	100.0%	3.3			
31/1	196.0	98.0	5.9	5.9	3.4	100.0%	14.3			
2/2	196.0	98.0	0.0	0.0	3.4	100.0%	21.1	8	20.0	0.0
5/2	196.0	98.0	6.2	6.2	3.4	100.0%	5.2			
10/2	196.0	98.0	6.6	6.6	3.5	100.0%	15.9	8	20.0	4.1
15/2	196.0	98.0	7.0	7.0	3.5	100.0%	10.6			
18/2	196.0	98.0	0.0	0.0	3.6	100.0%	21.3	8	20.0	0.0
20/2	196.0	98.0	7.4	4.9	3.6	100.0%	3.6			
25/2	196.0	98.0	7.7	7.7	3.6	100.0%	14.1			
26/2	196.0	98.0	0.0	0.0	3.7	100.0%	17.7	8	20.0	2.3
2/3	196.0	98.0	7.9	7.9	3.7	100.0%	6.8			
6/3	196.0	98.0	0.0	0.0	3.7	100.0%	21.7	8	20.0	0.0
7/3	196.0	98.0	8.0	1.7	3.7	100.0%	3.7			
12/3	196.0	98.0	8.0	8.0	3.8	100.0%	14.6			
14/3	196.0	98.0	0.0	0.0	3.8	100.0%	22.2	8	20.0	0.0
17/3	196.0	98.0	7.8	7.8	3.8	100.0%	5.9			
22/3	196.0	98.0	7.4	7.4	3.9	100.0%	17.8	8	20.0	2.2
27/3	196.0	98.0	6.8	6.8	3.9	100.0%	12.6			
30/3	196.0	98.0	0.0	0.0	3.9	100.0%	24.4	8	20.0	0.0
1/4	196.0	98.0	6.1	6.1	3.9	100.0%	6.1			
6/4	196.0	98.0	5.2	5.2	4.0	100.0%	20.7			
7/4	196.0	98.0	0.0	0.0	4.0	100.0%	24.7	8	20.0	0.0
11/4	196.0	98.0	4.2	4.2	4.0	100.0%	16.4			
15/4	196.0	98.0	0.0	0.0	4.0	100.0%	32.5	8	20.0	0.0
16/4	196.0	98.0	3.1	3.1	4.0	100.0%	13.4			
21/4	196.0	98.0	2.1	2.1	4.0	100.0%	31.5			
23/4	196.0	98.0	0.0	0.0	4.1	100.0%	39.6	8	20.0	0.0
26/4	196.0	98.0	1.2	1.2	4.1	100.0%	30.6			
1/5	196.0	98.0	0.5	0.5	4.1	100.0%	50.5	8	20.0	0.0
9/5	196.0	98.0	0.0	0.0	4.1	100.0%	63.3	8	20.0	0.0
17/5	196.0	98.0	0.0	0.0	4.1	100.0%	76.3	8	20.0	0.0
25/5	196.0	98.0	0.0	0.0	4.1	100.0%	89.3	8	20.0	0.0
26/5	196.0	98.0	4.0	4.0	4.1	100.0%	69.5			
31/5	196.0	98.0	10.4	10.4	4.1	100.0%	79.7			

2/6	196.0	98.0	0.0	0.0	4.1	100.0%	87.9	8	20.0	0.0
5/6	196.0	98.0	13.3	13.3	4.1	100.0%	66.9			
10/6	196.0	98.0	13.9	13.9	4.1	100.0%	73.5	8	20.0	0.0
15/6	196.0	98.0	13.4	13.4	4.1	100.0%	60.4			
18/6	196.0	98.0	0.0	0.0	4.0	100.0%	72.5	8	20.0	0.0
20/6	196.0	98.0	12.7	12.7	4.0	100.0%	47.9			
25/6	196.0	98.0	12.3	12.3	4.0	100.0%	55.7			
26/6	196.0	98.0	0.0	0.0	4.0	100.0%	59.7	8	20.0	0.0
30/6	196.0	98.0	12.7	12.7	4.0	100.0%	42.9			
4/7	196.0	98.0	0.0	0.0	3.9	100.0%	58.7	8	20.0	0.0
5/7	196.0	98.0	14.0	14.0	3.9	100.0%	28.7			
10/7	196.0	98.0	16.3	16.3	3.9	100.0%	31.9			
12/7	196.0	98.0	0.0	0.0	3.9	100.0%	39.7	8	20.0	0.0
15/7	196.0	98.0	19.5	19.5	3.9	100.0%	11.8			
20/7	196.0	98.0	23.3	23.3	3.8	100.0%	7.7	8	20.0	12.3
25/7	196.0	98.0	27.5	15.2	3.8	100.0%	3.8			
28/7	196.0	98.0	0.0	0.0	3.8	100.0%	15.1	8	20.0	4.9
30/7	196.0	98.0	31.5	3.8	3.7	100.0%	3.7			
4/8	196.0	98.0	35.1	18.6	3.7	100.0%	3.7			
5/8	196.0	98.0	0.0	0.0	3.7	100.0%	7.4	8	20.0	12.6
9/8	196.0	98.0	37.6	11.0	3.7	100.0%	3.7			
13/8	196.0	98.0	0.0	0.0	3.6	100.0%	18.2	8	20.0	1.8
14/8	196.0	98.0	38.9	0.0	3.6	100.0%	3.6			
19/8	196.0	98.0	38.6	18.0	3.6	100.0%	3.6			
21/8	196.0	98.0	0.0	0.0	3.5	100.0%	10.7	8	20.0	9.3
24/8	196.0	98.0	36.4	7.1	3.5	100.0%	3.5			
29/8	196.0	98.0	32.3	17.5	3.5	100.0%	3.5	8	20.0	16.5
3/9	196.0	98.0	26.6	13.8	3.4	100.0%	3.4			
6/9	196.0	98.0	0.0	0.0	3.4	100.0%	13.7	8	20.0	6.3
8/9	196.0	98.0	19.5	3.4	3.4	100.0%	3.4			
13/9	196.0	98.0	11.7	11.7	3.4	100.0%	8.6			
14/9	196.0	98.0	0.0	0.0	3.4	100.0%	12.0	8	20.0	8.0
18/9	196.0	98.0	4.3	4.3	3.3	100.0%	9.1			
22/9	196.0	98.0	0.0	0.0	3.3	100.0%	22.4	8	20.0	0.0
23/9	196.0	98.0	0.1	0.1	3.3	100.0%	5.6			
30/9	196.0	98.0	0.0	0.0	3.3	100.0%	28.6	8	20.0	0.0
8/10	196.0	98.0	0.0	0.0	3.2	100.0%	34.5	8	20.0	0.0
16/10	196.0	98.0	0.0	0.0	3.2	100.0%	39.9	8	20.0	0.0
24/10	196.0	98.0	0.0	0.0	3.1	100.0%	44.9	8	20.0	0.0
1/11	196.0	98.0	0.0	0.0	3.1	100.0%	49.6	8	20.0	0.0
9/11	196.0	98.0	0.0	0.0	3.0	100.0%	53.9	8	20.0	0.0
17/11	196.0	98.0	0.0	0.0	3.0	100.0%	57.8	8	20.0	0.0
25/11	196.0	98.0	1.5	1.5	2.9	100.0%	59.9	8	20.0	0.0
30/11	196.0	98.0	3.3	3.3	2.9	100.0%	51.3			
3/12	196.0	98.0	0.0	0.0	2.9	100.0%	60.1	8	20.0	0.0
5/12	196.0	98.0	4.6	4.6	2.9	100.0%	41.4			
10/12	196.0	98.0	5.4	5.4	3.0	100.0%	50.8			
11/12	196.0	98.0	0.0	0.0	3.0	100.0%	53.8	8	20.0	0.0
15/12	196.0	98.0	5.7	5.7	3.0	100.0%	39.9			
19/12	196.0	98.0	0.0	0.0	3.0	100.0%	51.9	8	20.0	0.0
20/12	196.0	98.0	5.8	5.8	3.0	100.0%	29.0			
25/12	196.0	98.0	5.7	5.7	3.0	100.0%	38.3			
27/12	196.0	98.0	0.0	0.0	3.0	100.0%	44.3	8	20.0	0.0
30/12	196.0	98.0	2.2	2.2	3.0	100.0%	31.1			
Total			679.9	446.2	1298.8	100.0%			900.0	81.6

Appendix G. Average of long term observed metrological data

Table G-1. Monthly weather data of Melkassa Research Center Station, average of 1977 to 2003

	Max T. ^0C	*Min T ^0C*	*Pan EV, mm/day*	*Total RF mm*	*Sun Shine Hr/day*	*RH %*	*Wind Sp. 2m Km/day*
Jan	26.91	12.00	7.57	14.10	8.95	48.00	11.12
Feb	30.50	13.50	8.31	26.65	9.05	49.00	11.55
Mar	30.61	15.31	8.61	50.86	8.29	49.00	11.14
Apr	29.44	15.93	8.31	51.85	8.18	54.17	9.94
May	33.01	14.05	8.48	51.85	8.93	39.28	9.56
Jun	30.11	16.59	7.53	67.75	8.44	53.35	11.57
Jul	25.88	11.57	5.74	185.73	7.06	68.59	11.50
Aug	25.11	16.05	5.35	181.07	7.18	71.30	8.64
Sep	26.67	15.23	5.58	82.32	7.31	69.32	5.84
Oct	29.19	11.73	7.38	41.84	8.55	43.00	7.73
Nov	28.29	11.75	8.15	7.63	9.68	41.06	10.17
Dec	26.17	12.67	7.71	10.79	9.46	48.16	11.22
Mean/Total	28.55	13.79	7.38	767.02	8.43	52.72	9.99

Table G-2. Monthly weather data of Nura Era State Farm Station, average of 1992 to 2003

	Max T. ^0C	*Min T ^0C*	*Pan EV, mm/day*	*Total RF mm*	*Sun Shine Hr/day*	*RH %*	*Wind Sp. 2m Km/day*
Jan	29.43	14.84	6.22	27.80	8.30	53.38	4.70
Feb	32.64	15.36	6.13	41.40	8.20	46.36	5.60
Mar	33.63	17.67	6.76	47.00	8.00	45.62	6.40
Apr	33.73	19.22	7.13	23.60	8.49	48.19	6.00
May	35.69	17.81	8.07	1.60	8.80	35.05	5.10
Jun	34.40	20.58	8.22	82.40	8.24	44.10	7.10
Jul	31.29	19.76	7.24	112.20	7.34	53.61	10.80
Aug	30.80	19.09	6.09	240.90	7.51	58.04	7.80
Sep	31.38	18.78	6.26	70.20	7.46	57.30	5.20
Oct	33.30	14.60	8.14	0.00	9.14	39.14	4.40
Nov	30.96	14.40	9.10	3.70	9.33	44.32	5.00
Dec	29.00	13.00	6.29	35.00	8.93	46.49	4.60
Mean/Total	32.19	17.09	7.14	685.80	8.31	47.63	6.10

Appendix H. Plates of field observations during the study

Fig H-1 Irrigation water wasted at Doni due to poor irrigation canal management

Fig H-2 Conditions of irrigation water during and after field application, Batu Degaga and Doni, respectively

Fig H-3 Soil sampling and applied irrigation water measurement (using parshal flume) to the farmers' field, Doni

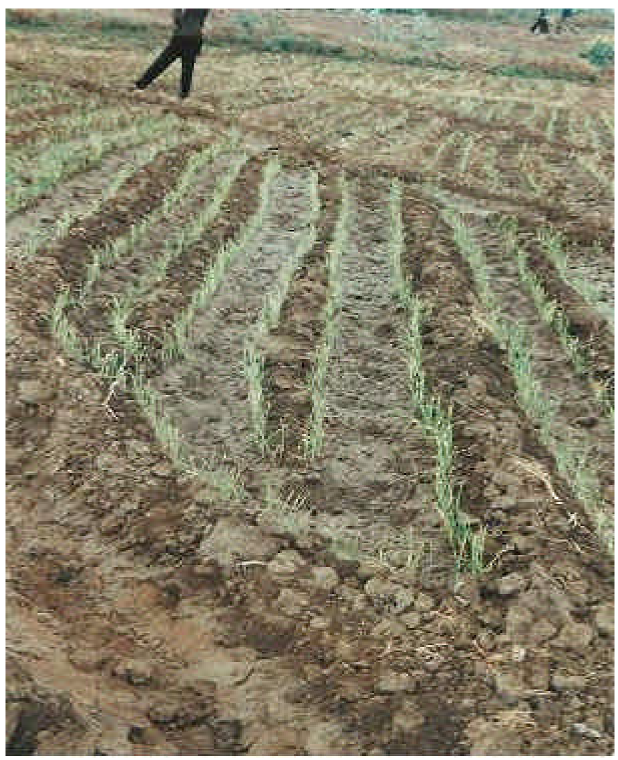

Fig H-4 Over irrigation may result in salt accumulation, Doni

Fig H-5. Discharges of the pumps of Batu Degaga were determined by volumetric method

Fig H-6. Discharges measurements of the main canal of Doni was carried out using current meter

Fig H-7. Pump house at Batu Degaga and excess water diverted flows back to the Awash River over the diversion weir

Appendix I Maps of the two irrigation projects

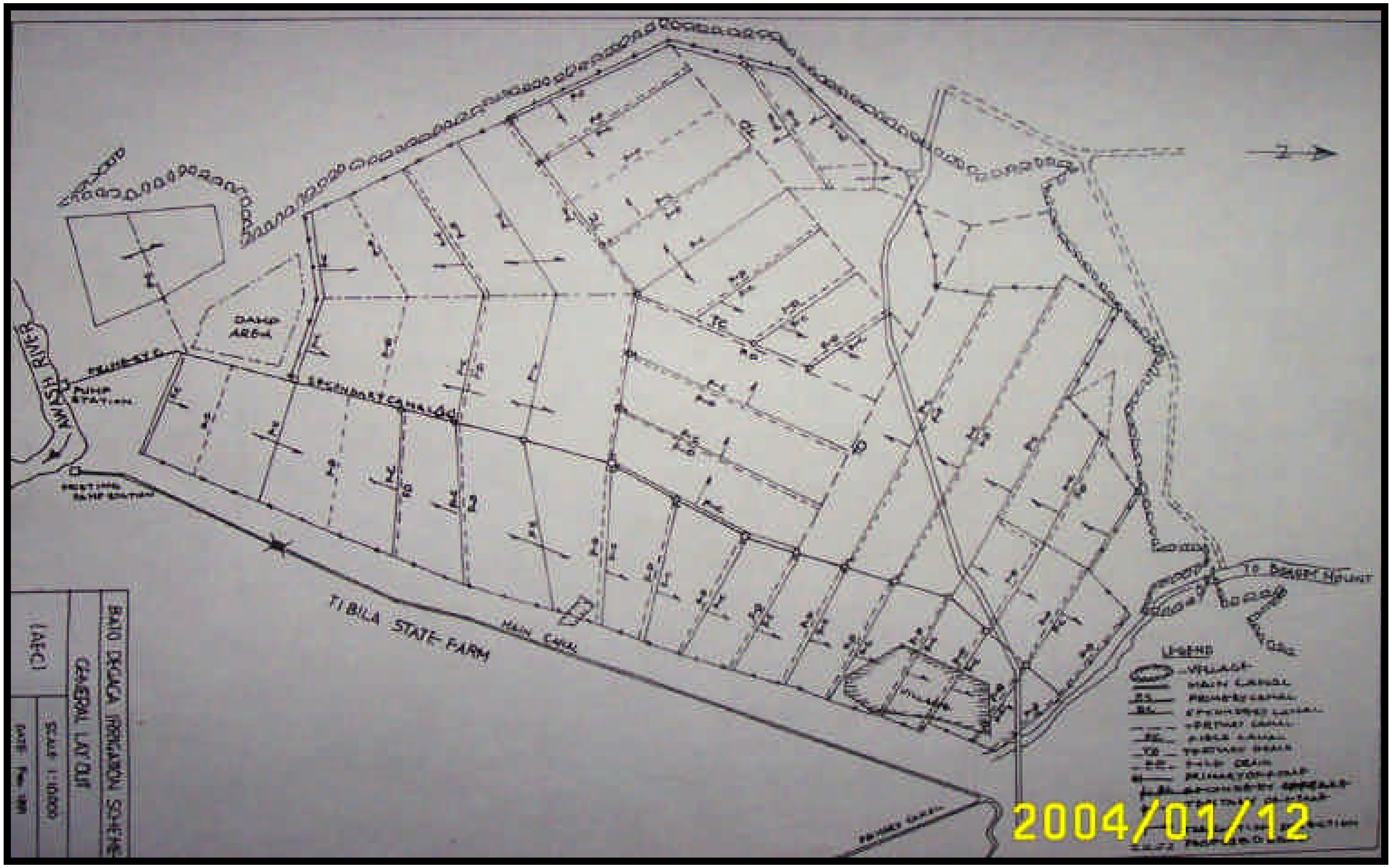

Fig I-1. Plan of the Batu Degaga irrigation project (source: ASE, 1990)

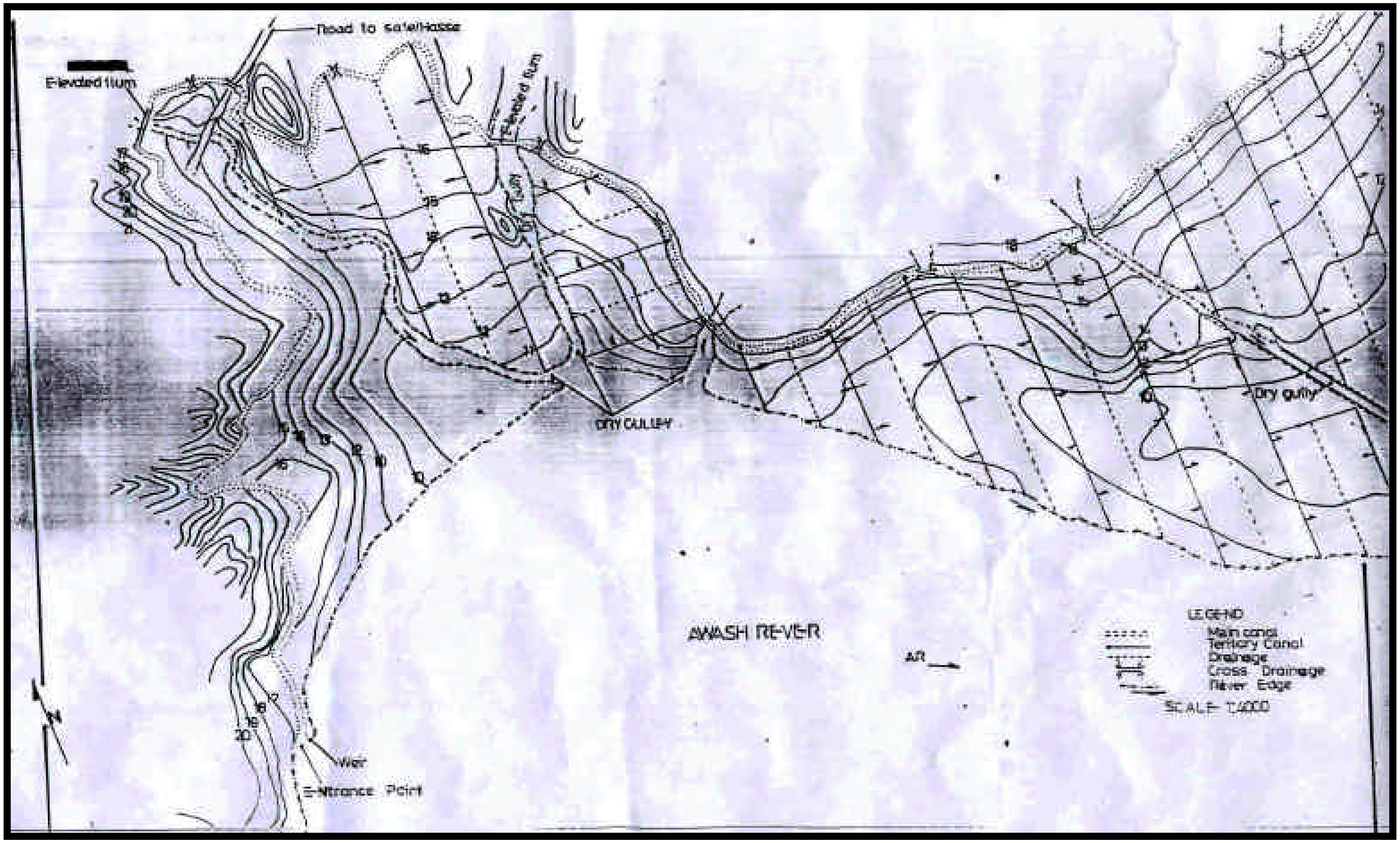

Fig I-2. Topographic map of Doni irrigation project (Source, from Oromia irrigation Bureau)