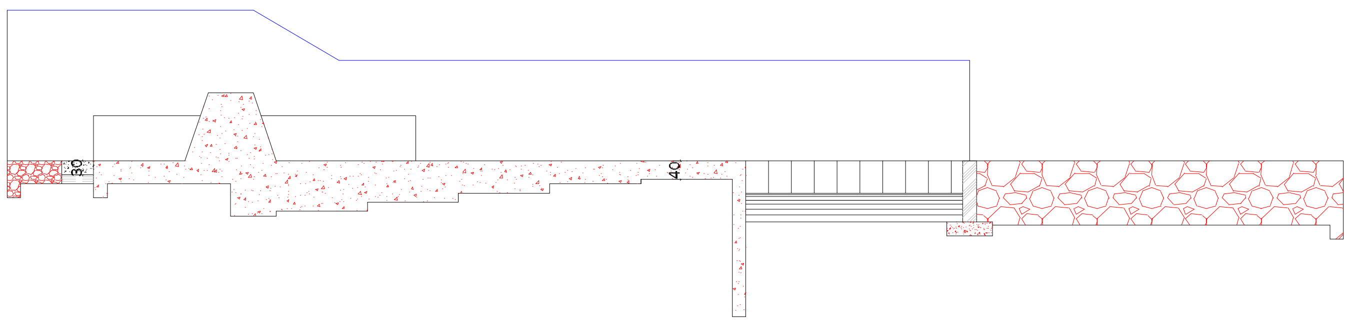
Planning, Design and Operation aspects of Diversion Systems for Irrigation Purposes

A Case Study of Kulanti Diversion Irrigation Project in Amhara Region



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LIST OF ACRONYMS AND SYMBOLS

Institutions and organizations

DAAD	Deutsche Akademische Austausch Dienst (German Academic Exchange Service)
ESRDF	Ethiopian Social Rehabilitation and Development Fund
FAO	Food and Agricultural Organization
IWMI	International Water Management Institute
MoA	Ministry of Agriculture
MoWR	Ministry of Water Resources
NGO	Non-governmental Organization
NMSA	National Meteorological Service Agency
ORDA	Organization for Rehabilitation and Development in Amhara
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
WUA	Water Users Association

Technical terms

AMC	Antecedent moisture condition
BOD	Biochemical oxygen demand
CBA	Cost benefit analysis
CEC	Cation exchange capacity
CN	Curve number
CRF	Capital recovery factor
CPC	Community project committee
CV	Coefficient of variation
D	Rooting depth
d_c	Depth of cistern
DO	Dissolved oxygen
d/s	Downstream
E_C	Critical energy
EC	Electrical conductivity
EIA	Environmental impact assessment
ET	Evapotranspiration
ETo	Reference crop evapotranspiration
ETc	Crop evapotranspiration
FC	Field capacity
FSL	Full supply level
FIR	Field irrigation requirement
GIS	Geographic information system
GPS	Global positioning system
Ha	Hectare
Hdr	Height of drop
IP	Irrigation project
IRDA	Irrigation development agent

Kc	Crop coefficient
Km^2	Square kilometer
Lc	Length of cistern
LGP	Length of growing period
masl	Meter above sea level
MFL	Maximum flood level
MRH	Mean relative humidity
NIR	Net irrigation requirement
O & M	Operation and maintenance
P	Management allowed depletion, fraction of the total available soil water
PCC	Project control center
PET	Potential evapotranspiration
pH	Measure of acidity or alkalinity
PRA	Participatory rural appraisal
PWP	Permanent wilting point
RAM	Readily available moisture
R-notch	Rectangular notch
RF	Rainfall
Re	Effective rainfall
TEL	Total energy level
TWL	Tail water level
Sa	Available water in the root zone
SCS-CN	Soil Conservation Service-Curve Number
TDS	Total dissolved solids
u/s	Upstream
w/c	Water course
y_c	Critical depth

Glossary of local terms

Bega	The non-rainy season
Belg	The secondary rainy season
Birr	The Ethiopian Currency and is equal to 0.07€ as of august 2008
Dega	Areas above 2,600 m (8,530 ft) where temperatures range from near freezing to 16 degrees Celsius. This is where most alpine and afro-alpine vegetation occurs.
Gota	A storage facility made out of mud reinforced with straw
Gottera	A storage facility for cereal crops made out of mud, straw and wooden poles sliced into reasonable sizes of 15-20 cm and have higher capacity than Gota. Straw and wooden poles are used as reinforcement materials
Injera	Thin bread used as a major food type in many parts of Ethiopia
Kiremt	The major rainy season
Kolla	Areas below 1,500 m (4,920 ft) with both tropical and arid conditions where temperatures range from 27 degrees Celsius to 50 degrees Celsius. “Bereha” is a general term that refers to the extreme form of kolla.
Tella	local beer
Woina Dega	Areas between 1,500 m (4,920 ft) and 2,600 m (8,530ft) where temperatures range from 16 degrees Celsius to 30 degrees Celsius. This is where most of the population lives
Wurch	Cold & moist; > 3200 masl; freezing cold; 800-1600mm precipitation; < 1% of the country

1 Background

The ability of the world's natural resources to provide the needs of its growing population is a fundamental issue for the international community. World population continues to grow at 1.6% per annum and at rates exceeding 3% per annum in many of the least developed countries (FAO, 1996). At the same time essential natural resources such as land and water are declining both in quantity and quality due to such factors as competition with industrial and urban demands, degradation and pollution. The basic problem is one of mounting pressure on natural resources. Limits to the productive capacity of land resources are set by climate, soil and landform conditions and by the use and management applied to the land. Sustainable management of land resources requires sound policies and planning based on knowledge of these resources, the demands of the use to which the resources are put, and the interactions between land and land use. Among those limited resources are water and potential irrigable agricultural land that lies adjacent to the rivers, the planning and design of which requires a comprehensive consideration of technical and institutional aspects.

The growing rate of intensity in agriculture and acute water deficit problems arising from rainfall shortage, uneven spatial distribution, the competition for water among different sectors of development (water supply, agriculture, industry etc.) cause an increase in water usage. This general truth calls for higher irrigation efficiencies in irrigated agricultural development practices. In order to design an irrigation project, it requires both norms and standards established from long research outputs and experiences or properly organized guidelines, manuals and/or standards. Out of the different irrigation scenarios, this paper tries to stipulate a comprehensive planning, design and operation aspects of diversion systems for irrigation purposes. The objective is to provide procedures, methods and techniques of diversion system planning, design and operation that need to be considered and appropriate in the context of Ethiopia; particularly Amhara region.

1.1 Problem statement

In spite of the highly variable and in many cases insufficient rainfall and the high incidence of drought, food production in Ethiopia is almost entirely rain fed. However efforts are being made by different international and local NGOs to promote irrigation in the country but the level of success is very much below expected. Disappointing results of irrigation development efforts in the past have often been associated with poor planning, appraisal and implementation of investment opportunities in the country (Nijman 1991; 1992). For sound planning and design there are a bunch of disciplines that need to be addressed and given optimum level of importance. These include technical, agronomic, socio-economic and environmental and related infrastructure facilities that enhance the feasibility of irrigation projects. General water availability given hydrological conditions of the area, climate, the source of availability of water, rainfall data including hydrological studies for water availability, quantum of water available vis-à-vis proposed storage capacity should be considered. Sources of irrigation water available at the head works in relation to the requirement should be analyzed. However, the area of land to be irrigated per unit of water depends on the farmers' local irrigation experience and cultural practices.

Appropriate structural and hydraulic design of diversion works, irrigation conveyances, drop structures, gully crossings and other ancillary works taking into account safety and efficiency should me made. Selection of suitable crops, cropping pattern for the project, computing crop water and irrigation requirements of the project need to be analyzed thoroughly. For the analysis of the water balance of the project, there is a need to study the climatic parameters of the area and conduct soil analysis for the farm to be irrigated. This called for the use of primary data besides the use of locally and regionally available secondary information for the fulfillment of this study. Since the water requirement for irrigation depends primarily on the extent of the irrigated area, soil structure and the crops to be grown, it was necessary to collect as much information as possible despite of the time factor.

The role of water users association and local cooperatives and marketing issues are addressed in the research paper. Exploring the consequence of irrigation schemes on the environment and the measures to be taken to reverse the ill effects of irrigation projects is given utmost concern. Socio-economic studies high lighted participation of the user communities in project formulation and site identification and their role in project operation and management to ensure project sustainability.

1.2 Methodology

Various methods of collecting data were employed to formulate the research work. Physical observation, individual farmer's interview, key informants interview, group discussions and general meetings were held during the study. General meeting was made with the community basically to assess different aspects of the project management by the community and find out the role played by them. Important information is also collected from office of agricultural development site and relevant offices at district level so as to know the role played by them during project design and implementation. Design document review was the major part of the research task. Primary data is generated by measurement of relevant parameters and conducting laboratory analysis at Water Resources Development Bureau of Amhara Region in Bahir Dar.

I Literature review

2 Technical considerations

2.1 Hydrological studies

When talking about hydrological studies, it is necessary to pay a glance to the hydrologic cycle which includes all the process in relation to water availability. It is a continuous process without beginning or end and can be defined as "the sequence of cyclic events which correlates the movement of water from the atmosphere to the earth's surface and then to the large water bodies through surface and subsurface routes and finally going back to the atmosphere" (Patra, 2003). Thus a hydrologic process undergoes the complicated process of precipitation, interception, evaporation, transpiration, infiltration, percolation, runoff and various storages as shown in Figure 1.

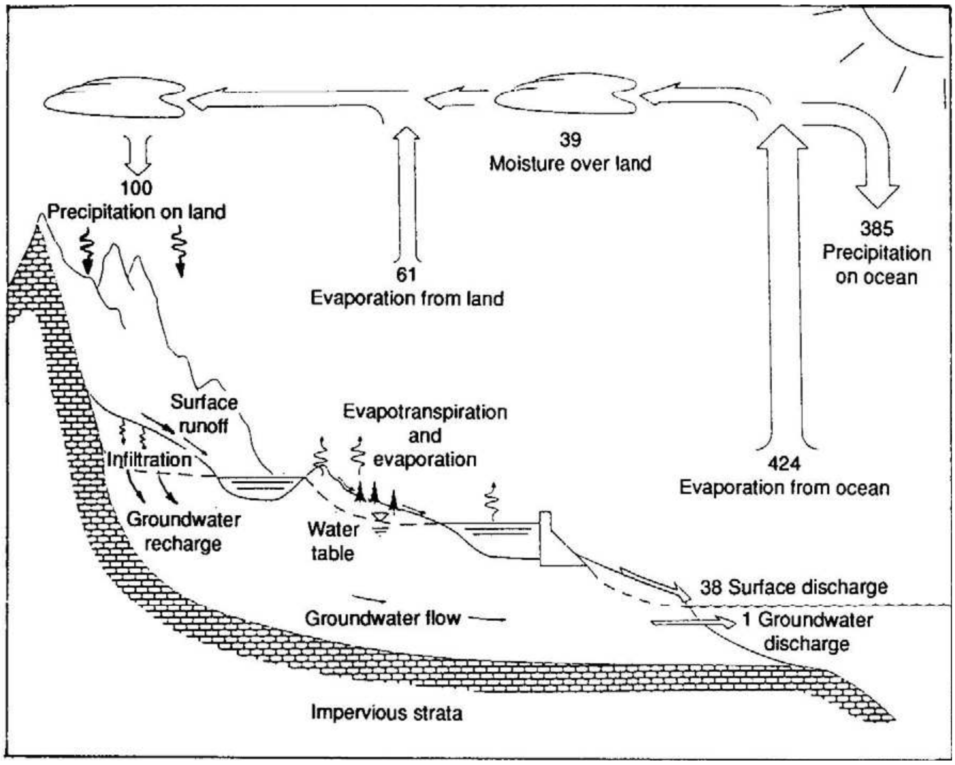


Figure 1 **The hydrologic cycle with annual volumes of flow given in units relative to the annual precipitation on the land surface of the earth (119,000 km^3/year) Buck , 2006**

2.1.1 Types of data required for diversion irrigation projects

In standard practice the data required for water resources development projects are prescribed by regulations appropriate to different areas of water resources planning. Irrigation development projects practice in many places indicate that for diversion irrigation systems, the following hydrological data are required to be available to carryout various types of hydrological analysis that have relevance to the planning, realization and operation of the project.

Catchment area measured on appropriately scaled map (1:25,000 or 1:50,000) and catchment physiographical characteristics (average catchment slope from the furthest catchment divide to the diversion site, average catchment elevation and slope of the main stream channel), precipitation on the catchment, stream flow, duration curve of daily mean discharges and flood peak discharges of recurrence interval of 50 to 100 years, free water evaporation in the catchment and suspended sediment and bed load transport are the primary ones.

2.1.2 Data quality assessment

Advances on the practice of engineering hydrology are dependent on good, reliable and continuous measurement of hydrologic variables. The measurements are recorded by a wide range of methods from the simple writing down of a number by a single observer to the invisible marking of electronic impulses on a magnetic tape. Although the most advanced techniques are used in the developed countries, many nations of the third world like Ethiopia employ direct manual methods. Therefore data collection, transmission, quality control, storage and retrieval should always be considered as one consistent information system, and as much attention should be paid.

For hydrological analysis of a water resource development project, it is important to make sure that time series of appreciable length are available and it is too late to start data collection when the data is needed. It is these hydrological variables that determine the potential of water resources. An effective system for routine collection, processing and quality control of data is therefore an essential part of hydrological services. Data should be accessible from those agencies and responsible agencies had to make their own quality control technique at various stages from collection to storage. Serious errors could be involved in measurement, recording and transferring of data. It is therefore, advisable to check the quality of the data before it is processed and used.

Rainfall data quality assessment

The value of rainfall data depends primarily on the instrument, its installation, its site characteristics and its operation by responsible observer. It is essential for a hydrologist using the data to have direct knowledge of a rain gauge station and authorities are recommended to keep the history of each station. A well documented up to date history of a rain gauge station is invaluable in assessing the reliability of the rainfall measurements and is an important first step in quality assessment and control. There are several types of errors that can occur on observer’s data registration cards. On first inspection some of these may be identified and corrected at once; some have to be noted and marked and others may remain undetected. The errors could be

i. Misreading, misplaced decimal points, copying errors and arithmetic mistakes,
ii. Accumulated readings over several days entered as if a one day total,
iii. Correct readings entered on wrong days, persistently or only occasionally,
iv. Inadvertent omission of observations made but not noted,
v. Occasional errors due to temporary disturbances of the gage or its exposure.

Therefore the quality of any rainfall data should be checked before it is used for hydrological analysis. First the data should be screened roughly and then it should be checked for the presence of trend or discontinuity, reliability and adequacy and consistency.

Rough screening

The data should pass rough screening by visual detection. This indicates whether the observations have been consistently or accidentally credited to the wrong data and whether they show gross errors.

Checking trend and discontinuity

After rough screening, the data should be plotted on normal or semi-logarithmic papers in the form of cumulative departure from the mean. The resulting graph can easily show any obvious trends of discontinuities. More objectively tests for randomness can be performed on time series basis to check whether or not any trend is present.

River flow data quality assessment

The hydrology department of the area should pay particular attention to the quality of flow records. The following types of errors are expected to occur.

i. Reading, missing a non-numeric character in a reading, a reading with incomplete digits. Single errors in a reading should be corrected by interpolation from adjacent readings but with two or more consecutive errors, the readings should be inspected.
ii. The difference between consecutive readings greater than the allowed one.
iii. The reading higher than the upper limit given for the station. For a sharp rise followed by a sharp fall (or the reverse), an interpolated value is inserted from the adjacent readings.
iv. The readings less than or equal to datum. Single low readings can be replaced by interpolation between adjacent readings.

In the complex path from the initial water level observations to the production of daily mean discharges, data quality checking should pass through the following four major phases as described for rainfall data quality assessment.

i. Rough screening
ii. Checking trend or discontinuity
iii. Checking reliability and adequacy
iv. Checking consistency

2.1.2 Flood analysis

Design flood is the flood magnitude which is expected to occur with a certain return period during the design period of a structure. The selection of the return period is generally based on safety, economy, size and category of the scheme and should be greater than the design period of the structure. The return period can be related to the annual exceedance probability (Patra, 2003) by

$$q = 1 - \exp\left(\frac{-1}{T}\right) \quad (1)$$

Where T is the return period in years
q is the annual exceedance probability in percent in which case both of them are indicating the rarity of flood events.

A project having 50 years return period has annual exceedance probability of 2% which implies every year within the 50 years period there is a chance of 2% that a flood exceeding the design flood may occur. In every case, the design period can be established through rigorous analysis of the available data (Chow et al., 1988).

Diversion dams, weirs and barrages have usually small storage capacities and the risk of loss of life and property downstream would rarely be serious with the failure of the structure. However, the structures are fairly large and costly. Apart from the loss of structure by its failure, irrigation and communications that are dependent on the structures would be disrupted. In consideration of these risks involved; diversion dams, weirs and barrages should be designed for flood frequencies of 50 to 100 years. Minor structures such as levees and drainage ditches can be designed safely for a return period of 2 to 50 and 5 to 50 years respectively (Patra, 2003).

Flood estimation for ungauged catchments

While planning diversion irrigation systems, it is common experience to come encounter rivers which have hardly any discharge data available. In such cases, the peak discharge for feasibility studies can be determined by the following methods. Rational methods, empirical methods, Envelope curves, Soil Conservation Service (SCS), using flood marks and flood levels obtained from inquiry, regional flood frequency method (using regional-frequency curve and a correlation between mean annual floods and respective catchment areas). Applying multiple linear regression model technique for 78 Ethiopian catchments ranging in size from 20 km^2 to 66,000 km^2, available flow data of ungauged streams are related to their respective catchments (Gebeyehu, 1989) by

$$Q_{Max} = 0.87A^{0.7} \tag{2}$$

Where A = Catchment area in km^2

Q_{max} = Mean annual flood in m^3/s

The equation above is a regional relationship of stream flow characteristic and catchment characteristics in Ethiopia which is expected to be more realistic for the Ethiopian condition rather than empirical equations developed for other countries conditions. However; it is better to use regression equation for smaller (homogenous) regions of the country whenever such equations are developed (MoWR, 2002).

2.1.3 Low flow analysis

During a dry season of a year, minimum flow of streams should be recorded and critical periods of water shortage need to be indicated. To maintain supplies of water, there should always be concern with resources during periods of low flow and the increase in demand that dry spells generally stimulate. A thorough knowledge of those rivers providing water supplies is essential. In perennial streams it is desirable to maintain a defined minimum discharge. This is particularly important in all rivers receiving waste water effluents in order to insure required dilution of pollutants and to maintaining the aquatic life and stabilizing the environment.

Low flow would be limiting mainly for irrigation or water supply schemes that are served by diversion and it is necessary to make low flow analysis for these schemes. If the dependable low flow in a given period and the demand for irrigation that is based on crop water requirement are known, then sequent peak algorithm method can be applied to analyze the flow and find out whether it satisfies the demand without storage or not (MoWR, 2002).

$$S_t = D_1 - I_1 + S_{t-1} \tag{3}$$

Where

D_1 = demand m^3/s

I_1 = Inflow, m^3/s

St-1 = Previous required storage, m^3/s

St = currently required storage, m^3/s

2.2 Diversion system

Prior to designing a diversion weir, the prerequisite procedure is to follow a project cycle. The use of the project study and design cycle assists in evolving the most viable solutions. Technical issues that need to be considered in the design of diversion systems include but not limited to the following: Proximity to the irrigable area, presence of stable banks, preferably gravity supply to irrigable area, economical size of the structure (short crest length, moderate height of weir). It is worth to note that at the reconnaissance and identification level; technical, social and environmental assessments should be done but not at depth due to the limited amount of data to be collected by then.

2.2.1 Aspects of diversion system design

Once the diversion site is selected at reconnaissance and identification level, the next step should be to study the site at feasibility level and to select the type of diversion and define the components of the structure before conducting the detailed design which needs decision at feasibility level. Regarding location of the diversion site, topographic maps of appropriate scale say 1:50,000 or better need to be used to initially locate the diversion site. Subsequently field assessment should be followed in order to identify few alternative sites (here use of local farmers information is highly recommended). The proposed axis of alternative weir sites have to be made on a map based on the assessment. Use of hand held GPS is useful to determine the coordinates of the two end points of the axis and other important ground elevations and coordinates.

Under optimum conditions, the diversion site should be located neither very close to the irrigable area so as not to miss gravity command area nor very far so as to avoid very long idle reach of main canal that would inflate project cost. Therefore a rough cost and benefit analysis should be made before decision. Assuring the water tightness and stability of the abutment and river bed is quite important once the diversion site is selected. From the hydraulic point of view, the most suitable location for a diversion structure is where the river is straight, has stable banks and no deposit islands are formed. Where a straight reach can not be found, the weir outlet should be built on the outside bank of a bend where the river even at its minimum discharge can supply the main canal with adequate water and sedimentation is less.

Requirements for effective water diversion from streams into an irrigation canal include the creation of an obstruction or a barrier for the following reasons: To guide stream flow into the canal system, to raise water level, to reduce fluctuation of water level in the stream, to regulate flow rate of the stream. Moreover it also requires regulatory structures for the following purposes: To prevent river flood from entering into the canal, to allow a regulated discharge to pass into the canal and to prevent excessive silt from entering into the canal.

2.2.2 Components of a diversion system

The major components of weirs and barrages are basically the following. Weir / or spilling section, divide wall, under sluice/scouring sluice, head regulator, silt exclusive device, upstream and downstream apron, cut off walls, filters, gates, energy dissipation devices and river training works such as retaining walls. The design and sizing of each component had to be addressed for proper hydraulic functioning.

Weir/spilling section

In selecting the type of crest or spilling section to be used in the design of a diversion structure for a particular site; the following factors are to be considered especially under the Ethiopian context. These are character and strength of foundation, availability of construction materials, necessity for a controlled crest, cost and last but not least river morphology as related to sediment transport based on the nature of river (perennial and intermittent). As can be easily noticed most perennial intermittently flowing rivers particularly in the northern portion of the country are characterized by the river morphology which carries quite significant volume of suspended and bed load, where the bed load has sizes of boulders ranging from few centimeters to 75 centimeters (ESRDF, 1997).

This calls for a special consideration that allows the passage of this bed load right after the first occurrence of the flood flow season. The sediment flow nature of a river mainly depends on the morphology of the river and not every river at the lowland reach has high bed load. In instances where rivers carry high bed loads with sizable boulders, pebbles and cobbles, it is advisable not to restrict the passage of these bed loads but rather facilitate the quickest possible release below the weir axis. The type of bed load that the river carries directly affects the type of weir crest that needs to be designed (whether ogee or broad crest).

Divide wall

It is a long solid wall that should be constructed at right angle to the weir axis and divides the river channel into two compartments-small and bigger. The smaller compartment which is nearer to the head regulator is used to create a stilling pond to be used by head regulator. Divide walls extend from the weir body to a little beyond the length of the head regulator and it is generally constructed from masonry works and seldom using reinforced concrete.

Under sluices

These are openings provided in the body of the weir and used to evacuate /flush / or scour the sediment deposition in front of the head regulator. Normally the sluice's invert level is 1.0 to 2.0 m below the invert level of the head regulator for small and medium scale irrigation projects (Kumar, 1989). The sluicing effect maintains the channel clear and defined in front of the head regulator. More over sluices are used to decrease the flow over the crest during peak flow period.

2.2.3 Hydrologic and hydraulic design of diversion systems

Engineering hydrologic design

The following parameters of design need to be considered when dealing with the hydrologic design of diversion weirs.

Maximum design discharge that corresponds to a return period of 50 or 100 years is evaluated for small or medium scale diversions. The maximum design discharge is used to determine the weir crest length and to determine the back water curve and also the water afflux which is the water level difference upstream and downstream of the weir axis.

Lean flow (minimum discharge) should be selected from monthly minimum values if recorded data is available or through drought analysis by selecting appropriate return period.

The rate and nature of sediment transport is required to determine the type of weir structure to be at the weir crest, head regulator and scouring sluice invert levels.

Rating curve at the location of the weir needs to be known. The curve is constructed from the river stage and discharge measurement records. If the natural stream records are not available theoretical rating curve should be constructed.

Downstream release

Sufficient flow that would allow maintaining the aquatic life and environment stabilization should be released downstream of the weir site. The flow should not be totally curtained and drying up the river channel in the lean flow season should not be allowed.

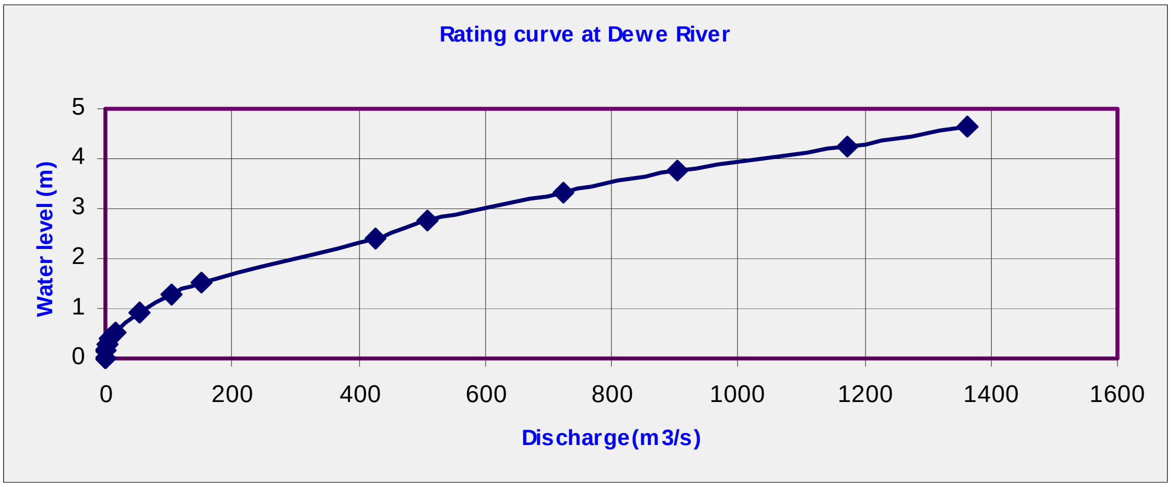


Figure 2 Stage discharge curve, ORDA 2003

Hydraulic design

The hydraulic design basically refers to the surface and subsurface flow analysis and design of the hydraulic structure. The crest elevation of the weir needs to be determined considering the head regulator invert level, sediment deposition rate if storage is required and limitation of upstream afflux level. The shape of the weir crest is determined from design and construction simplicity and hydraulic efficiency. For most small scale weirs, ogee shape may not be recommended while it is almost mandatory for medium scale.

The designer needs to prepare the *water surface profile* upstream and downstream of the weir axis for the following reasons.
At upstream of the weir axis to determine the safe level of upstream property and super structures that could be flooded and to find out whether canal intakes for which the weir is built receive water at all stages of the river and to select the type of weir.
The water surface profile at downstream of the weir axis is used to carry out the stability of the weir and to conduct the structural design considering uplift and piping, to determine the length of the hydraulic jump and to design the downstream wing walls and protection works downstream of the apron.

Structural design

The structural design of weirs has much to do with the nature of the foundation; permeable or non-permeable. The analysis of the design for both foundation conditions is the same except that weirs on permeable foundation need additional analysis regarding *piping and uplift pressure*. Therefore these aspects have to be properly analyzed. The forces acting on weirs can be generalized as follows: Static water pressure, uplift water pressure, soil reaction at weir base (foundation), friction forces at the base and weight of weir (self weight).

Major structural design aspects include piping, uplift, hydraulic jump, stability against overturning, stability against sliding and foundation bearing capacity. Piping is undermining of soil under foundation due to excessive percolation with sufficient pressure to dislodge and to lift soil particles. This has to be checked against safe exit gradients. Uplift is the excessive upward pressure exerted due to the percolating water and if the apron is not thick enough it may fail by rupture. Determination of the jump length in weir design is crucial to the design of the type of energy dissipation facilities. Finally the stability of the weir has to be checked against sliding and overturning forces and should be within desirable limits to ensure its safety.

Special considerations

River training or protection: The weir structure must be protected from the following adverse factors: Incoming surface runoff, scouring flow at the down stream end and creeping water along the side walls.
Upstream and downstream protection works: The most commonly used protection is riprap in a form of dumped rock or pre-cast concrete block or rock filled gabion (wire container).

2.3 *Irrigation system layout for farmer managed schemes*

Layout is the way in which different parts of an irrigation system are connected to each other. The objective of surface irrigation layout planning is to establish the optimum arrangements, positions and levels of canals and structures to ensure satisfactory irrigation water distribution and drainage at acceptable cost while taking account of the physical, technical and social constraints. The irrigation system as a whole consists of four subsystems (Bosch et al., 1993). These are:

i. The water supply sub system
ii. The water delivery sub system
iii. The water use sub system
iv. The water removal sub system

A layout can be represented on a map. A layout map shows location of the head works, irrigation canal system and alignments, drainage canal system and alignments, boundaries and approximate areas of the irrigation system with the primary, secondary and tertiary blocks, location of structures, road system and alignments, non-irrigable areas (unsuitable soils, too high areas) and flood protection areas and in certain circumstances cattle corridors.

Topographic data must be collected on the relative elevation of the source of supply, the land surface between the water source and the area to be irrigated, the different parts of the farm area to be irrigated and the drainage outlets in order to properly plan an irrigation system. Study of different layout alternatives based on basic layout principles and economic evaluation is an imperative until the final best fitting economical layout is obtained.

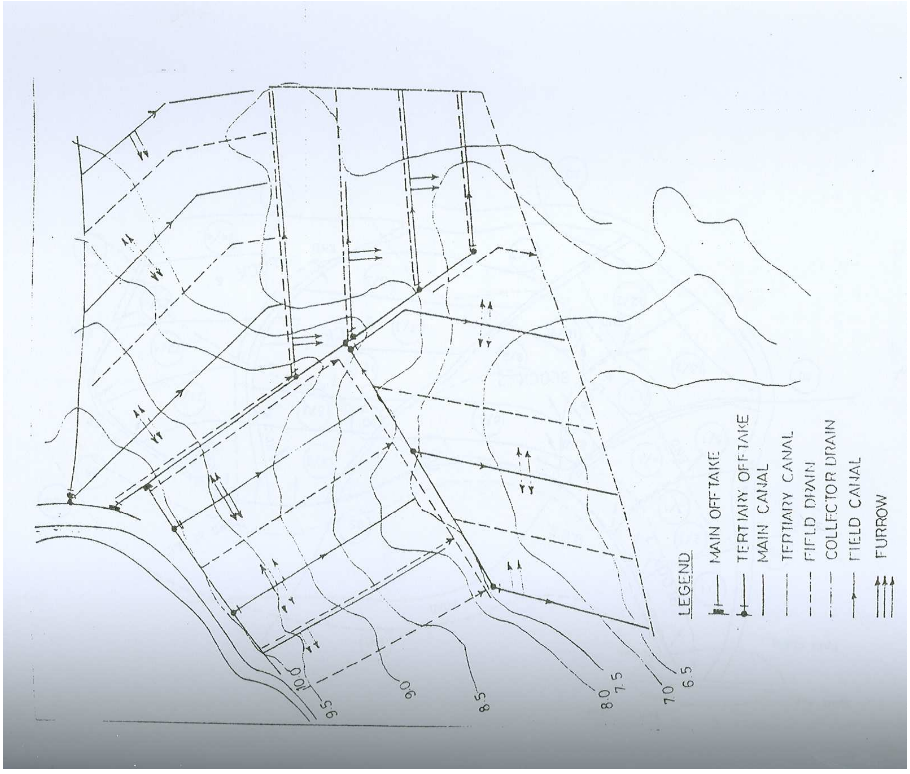


Figure 3 **Schematic diagram of distributaries' network, MoWR 2002**

2.3.1 Stages in irrigation layout

For proper layout design of an irrigation network, it is crucial to undertake the layout design in stages.

Stage 1: For the preparation of the preliminary layout plan, topographic maps at a scale of 1:2000 to 1:2500 have to be used for small scale irrigation projects. Maps at these scales show sufficient terrain information to allow proper interpretation of terrain features. Contour maps should be indicated on maps with intervals of 0.5 m for flat areas and intervals of 1.0 m for areas with terrain slopes of more than 2 percent (Bosch et al., 1993). The preliminary layout prepared serves as the basis for the preliminary canal design. Layout adjustments are often necessary to obtain a better (more economic) canal design solution. Alternative layouts need to be reviewed before the best preliminary layout is obtained.

Stage 2: The canal alignment as indicated on this layout is set out and surveyed in the field yielding an alignment and longitudinal section with levels. In addition main features, gullies, crossings and cross sections at appropriate intervals (based on the total length and the topography of the canal route) is done for engineering cost estimation and reconsideration possibilities and the last stage is modifying the preliminary layout based on ground truth inspection/verification.

2.3.2 Basic layout considerations

Selection of a canal route depends on topography of an area, geological conditions along the alignment of the canal, canal type, type and size of an irrigation project. The canal water surface profile (FSL) along the selected route should satisfy the requirements of:

i. *Command***:** A canal should divert water from a supply source at a position of sufficient elevation to reach the land to be under irrigation by providing proper gradients and using more economic route.
ii. *The various causes of high canal embankment failures* such as overtopping due to insufficient free board, excessive settlement of canal banks, under sizing of canal sections and seepage failures such as piping need to be seriously addressed.
iii. *Safety against seepage failures***:** If the canal section is partially or entirely in fill, consideration should be given to the use of compacted embankments or other suitable means of preventing excessive seepage and percolation through the fill. Carrying a canal in high embankment involves risk of breaches from percolation and hence careful judgment has to be exercised in fixing the points of cross drainage works.
iv. *Safety against structural design failures* such as canal bank slides caused by shear failures, liquefaction slides, for example fine sand and silt subjected to vibration are prone to liquefaction, earth quake causing excessive settlement due to which free board is reduced that results in overtopping of canal banks. Thus for safe design of high canal embankments the following basic criteria should be satisfied: No overtopping, no seepage failure, and no structural failure, provision of proper slope and drainage protection and selection of an economic section.

v. *Distribution:* At turnouts the canal water surface must be high enough to permit irrigation of the land located at far end and the high patch of area and
vi. *Least annual cost including maintenance:* In consideration of economy, deep cuttings or high embankments should be generally avoided by suitable detouring after comparing the over all costs of the alternative alignments. It should be tried that alignment of a canal crosses least number of cross drainages as possible as it could be.

The area to be irrigated and the source of supply dictate the planning and layout of an irrigation system. It is influenced also particularly by agricultural, engineering, and economic characteristics of the area. In addition existing land use practices and socio-economic conditions of the area need to be considered. A first step in layout design is the determination of secondary units. The main physical terrain features such as rivers, creeks and natural drainage pattern should be considered as the boundaries for the irrigation project or for part of it. Major roads may also be considered as boundaries of secondary units.

Once the boundaries for the secondary units are established, a preliminary division into tertiary units is made. The command area has to be divided into tertiary units consisting of blocks of fields to facilitate irrigation of the land evenly. The area to come under the tertiary unit is to be determined by topographical and land consolidation considerations. The tertiary units are to be sub divided into farm areas. The irrigation of each of the farm is done through field channels taking off from tertiary units through division boxes. Field channels are located along the upper reach of irrigation runs to supply water to the fields. They are usually perpendicular to the direction of irrigation for surface irrigation methods. The water surface in field channels must be 20 to 30 cm higher than the ground to be irrigated. If possible these channels should be nearly level (less than one percent slope) so that water can be checked up for a maximum distance (Bosch et al., 1993). Where the topography permits, the water supply canals may be so located so as to serve the field on both sides of it.

Layout of fields of workable size and shape is important to successful irrigated farming. The fields are laid out as nearly rectangular as possible. Sharp turns in field boundaries should be avoided as far as possible in order to facilitate use of modern farm equipment. The field length is based on the maximum allowable length of run for the irrigation method selected. Alternatively the field lengths may be limited by ownership boundaries. The width of the field depends on cropping system, operation schedule and type of farm equipment used. Field roads are provided above irrigation channels and below field drains that are readily accessible for working on the farm. To prevent water logging, interceptor drains may be necessary at the upper boundaries of the low lying area to divert seepage from over irrigated areas at higher elevations and irrigation canals.

2.3.3 General alignment procedures

The basis for a general layout map is a topographic map with contours at a scale of 1:2000 to 1:2500 showing the land configuration, spot elevations and important land features for the whole project area. Detailed layouts for the irrigation scheme are prepared or produced preferably at larger scale and for tertiary units even at larger scales. The following are the general alignment procedures.

i. An alignment of all canal grades (primary, secondary and tertiary) is marked on the map. Alignments consist of straight lines as far as possible. Connections between straight sections are circular curves with radii increasing with the size of the canal and thus depend on the design discharge.
ii. In irrigation system alignments of the primary canal run commonly more or less closely to the contours (as contour canals) with the off-taking secondary canals a long the terrain ridges. The primary canal should be generally carried on a contour alignment until either it commands the full area to be irrigated or it attains the top of watershed. From such a point it should be aligned down to the watershed ceasing to be a contour canal. After reaching a watershed the primary canal should be located along the main watershed and the secondary canals are planned on secondary ridges or if no clear ridge is present more or less in between the bordering drainage canals. Alignment design for secondary canals often with sufficient ground slope is therefore a straightforward procedure.
iii. Secondary and tertiary canals should take off from a canal or near the points where the canal crosses watershed. Tertiary canals are to be aligned as watershed or side slope canals. Tertiary canals are to be spaced suitably depending on the configuration of the area. The alignment of contour canals especially in the upper reaches is decided after careful consideration of economy. Thus alternative alignments, their benefits and costs have to be compared.

2.4 Distribution systems

The distribution system of an irrigation scheme is defined as the network of canals (or pipes) and associated structures which convey water from the source works to the cropped areas in a controlled way. Every surface irrigation scheme has a drainage system complementary to the distribution system for removal of surplus water, particularly excess rainfall and canal escape flows. The objective of the distribution system is to deliver the right amount of water to the right place at the right time to meet crop needs of the area to be irrigated without causing damage to the soil or excessive loss of water. Ideally water should be distributed equitably among farmers according to their needs.

2.4.1 Types of distribution

The delivery (distribution) system used by the water supply organization is called a scheduling system or schedule. Scheduling is the most common form of distribution. Principal variables in schedules consist of: the delivery frequency to the farm, the delivery flow rate which depends on the mode of distribution used: continuous supply, supply on rotation, or supply on demand and the delivery duration. The relation between these three factors control the capital cost and operating expenses of the delivery system.

The same factors bear heavily on the effective and economical use of water, labor, energy, and capital investment on the farm. It may even limit the crops that can be considered. These may be varied singly or in combination to deliver the required volumes in the relevant time periods at the appropriate intervals. In general the farm water delivery policy must be compatible with the distribution system on the farm. The challenge in designing a collective irrigation system is to attain a good degree of flexibility at a low cost. A very flexible system allows for a larger stream size and a shorter irrigation interval but is more costly because it requires large capacity conveyance network. Some of the principal factors affecting distribution systems are described below.

Factor	***Impact on distribution system***
Scheme size	Affects number of levels in the canal hierarchy
Source of water	Scheme fed from one (usually surface) source are a single entity with a canal hierarchy. Schemes fed from multi sources (e.g. ground water) normally comprise a number of discrete substances.
Topography	Hilly schemes often comprise a long canal feeding small pockets of land along its length, tending to give a “one dimensional” effect. Flat plain schemes tend to be more “two dimensional“. Features such as natural channels, village boundaries, etc often determine the forms of distribution units.
Demand and supply driven	The components of the system are determined whether water is to be supplied continuously according to a schedule or on demand in which case storage may need to be provided to cope with peaks and variations in demand along with appropriate structures.
Flow variation	Large variations in flow availability influence the rotational system chosen.
Management	If the management capability to operate the system is low it may be preferable to provide semi-automated systems (e.g. proportional distribution) so that gate operations are minimized even if the distribution objectives are partly compromised.
Charging	Charging farmers for water by volume may require the installation and operation of measurement devices.

Schedule (mode of irrigation water distribution) types may be broadly classified as on demand, rotation, or continuous flow. Combinations of two or more of these methods may be used in any system depending on the location of the farm with respect to the distribution system, the seasonal water requirements, or the available water supply.

The demand schedule in which the irrigator may have water as desired i.e. flexible in frequency, rate and duration. This schedule represents the ultimate in freedom to the small independent cultivator. The capacity of such a system would be too large for reasonable capital and operating costs since it must be large enough to meet the combined probable demand of all the users at any one time. Though on demand systems would seem to be the best solution in terms of satisfying farmers, they have seldom been adopted because of the high cost. Where they have been used the returns (in terms of crop yields) are reported to be higher than other types of system. It is possible to convert a scheme designed for continuous or scheduled flow to an on demand system by installing on farm reservoirs that store the continuous or scheduled flows until actually needed. However, this does presuppose that there is sufficient head in the canal system to provide a suitable storage depth (or pumping is used) and that the farmer is prepared to give up land for the purpose of storing water.

All scheduled systems use some forms of rotation between farmers or groups of farmers. One of the principal problems of this is the conflict which arises when one group of farmers is receiving more than other groups. This distribution mode is based on the condition that the area to be irrigated is divided into tertiary units each of which is again divided into a number of blocks; each block is assigned a fixed rate of water supply depending on its area. The flow to each block is continuous at the fixed rate and the different farms within the blocks are supplied with the whole flow on rotation at a predetermined time period. Both the timing and amount of water to be delivered depend on that surface area and the cropping pattern of the farm.

If rotation system can be made to work the result is a cost effective means of distribution. However, this requires good cooperation between farmers, effective management of operation and maintenance and good design. In practice these are difficult to achieve. In the interests of simplicity of operation, irrigation releases are scheduled so as to meet the needs of a pre-selected major crop in the area and the cultivators plan, their cultivation, planting, irrigation etc. To conform to these schedules of releases, prerequisites for such a system are:

i. A predictable, well regulated supply of water,
ii. Reasonably uniform soils through out the service area
iii. Preferably an alternative source of supplemental supply for those cultivators who wish to differ radically from the pre-selected crop.

2.4.2 Canal measuring and regulation structures

In the management of an irrigation system, it is important that the flow at canal bifurcations and off-take structures be measured accurately. In this way the available irrigation water can be supplied to areas where it is needed and misallocation of water can be avoided (Bos et al., 1984). Generally there are different types of irrigation farm structures each with their own particular function. Discharge measuring structures, discharge regulating structures and flow dividers. In selecting a suitable structure to measure or regulate the flow rate in an open channel, considerations and criteria for the selection of canal discharge measuring and regulating structures include (USBR, 2001).

i. Hydraulic performance,
ii. Need for standardization of structures,
iii. Ease with which discharge can be measured or regulated i.e. reduction of operation costs,
iv. Availability and cost of local material and labor and
v. Anticipated service life of the structure.

Although other criteria listed above come into play in the final selection of a discharge measuring structure or regulating structure, hydraulic performance is fundamental to the selection. Hence the following factors are to be considered in the selection of appropriate structures based on hydraulic criteria. Function of the structure, the available head and the required head at the discharge measuring site, range of discharge to be measured, sensitivity i.e. variation of the discharge because of a unit change of upstream head, the ease with which they pass bed load and suspended load, undesirable change in discharge, minimum water level in upstream channel, required accuracy of measurement and standardization of structure in an area.

Canal discharge measuring structures

Flow need to be measured at the head of the primary canal, at canal bifurcations in the primary system and at secondary and tertiary off-takes. Measuring devices can be divided into free overflow and underflow devices. The most commonly used water measurement structures in canals and laterals are Parshall flumes, fixed weirs, and constant head orifice structures. The choice between one and the other depends on the expected flow rates and site conditions.

Table 1 Recommended canal discharge measuring structures at various locations in the irrigation system, Bos et al., 1984

LOCATION IN THE IRRIGATION SYSTEM	***RECOMMENDED DEVICE***
At head of primary canal.	For large flows a broad crested weir for measuring and flat sliding gates or radial gates for regulating.
At division structures or secondary off-takes.	If flow rates are too large, a broad crested weir in combination with sliding or radial gates.
At tertiary off-takes.	Gated pipe off-takes may be considered for small tertiary units along a primary canal with large water level variations.

Weir

The weir when properly constructed and installed is one of the simplest and most accurate devices for measuring irrigation water and most frequently encountered at check structures in the water delivery network. From the different types of weirs for canal flow measurement, 90^0 V-notch weir and broad crested weir are the most commonly used ones for small discharges.

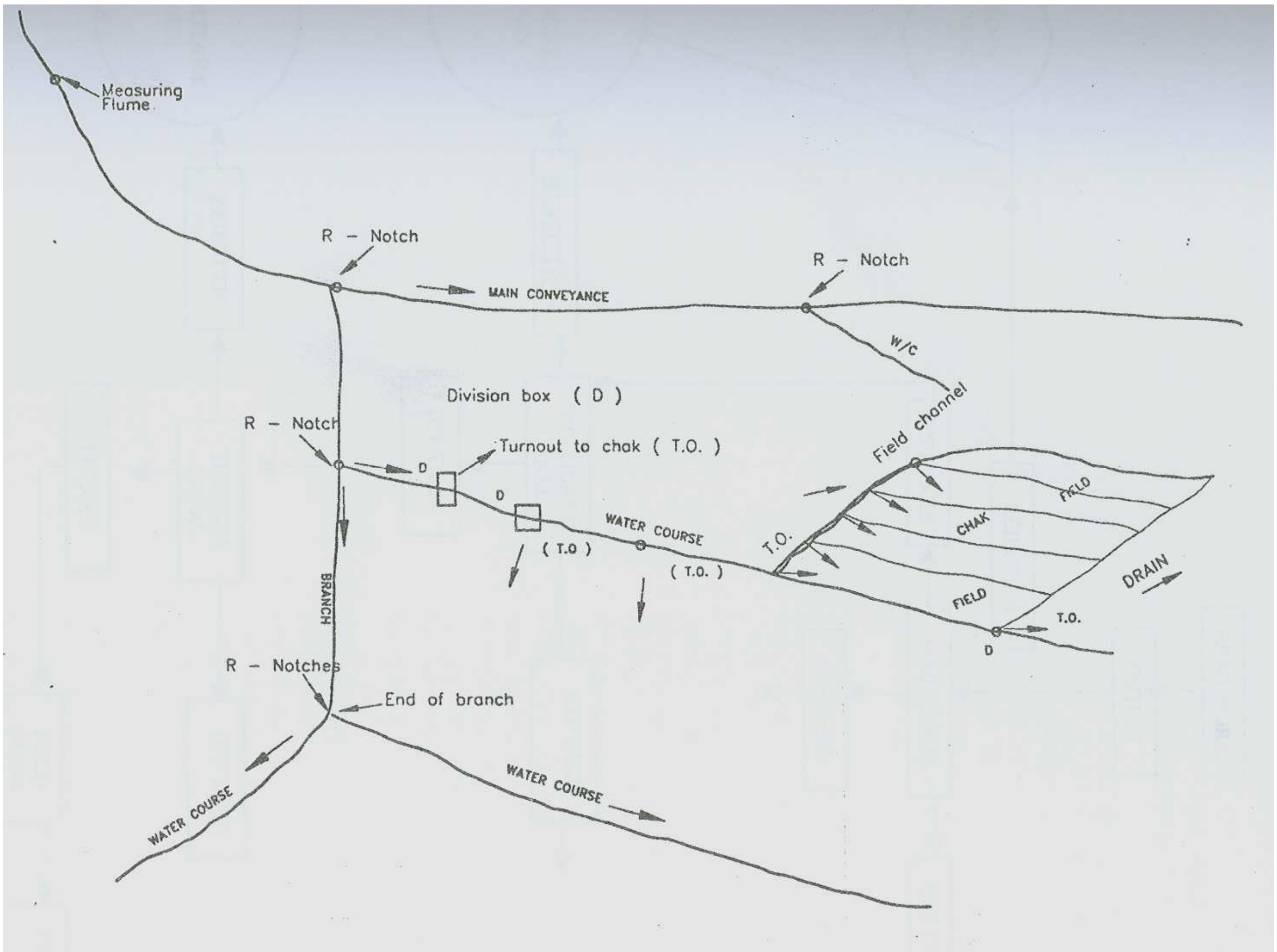


Figure 4 Location of flow measuring structures in the network, MoWR 2002

Parshall flume

Another canal flow measuring structure that is specifically shaped for open channel flow section. The flume has the advantage of measuring the discharge at low head losses and the velocity of flow has to be high enough to avoid sediment deposition in the flume section.

Canal discharge regulating structures

These structures have discharge measuring function and as well as serve to regulate the flow and so distribute regulated flow over the irrigated area. Discharge regulating structures are needed at places where the canal water level is affected by a drop or chute. A discharge regulating structure is equipped with movable parts. If the structure is a weir, its crest is movable in vertical direction; if an orifice (gate) is utilized the size of the opening can be variable. It is thus important to note that in canal irrigation systems the discharge can be *regulated and measured by one structure*.

Figure 5 Effect of a scoured drop structure on the canal full supply level

2.4.3 Internal and external drainage systems

In an internal and external drainage system study, it is necessary to conduct topographic, geologic and soil surveys. The properties of the soil especially the permeability should be determined. The moisture content in the soil markedly affects the oxygen content of the soil in the soil pores. The depth of the water table below the ground surface has to be ascertained. Moreover, the fluctuation of the water table during the year should be studied. The type of drain most suitable for a particular site depends upon the purpose for which the drainage system is required. As drainage system is quite expensive, economic analysis should be done. A drainage system that gives the optimum degree of relief for a given investment needs to be selected. This can be achieved by artificial drainage (man-made channels) through which water is carried away to natural drains.

Apart from ill aeration of plant, many other problems are created due to water logging. The most common symptoms of water logging are:

i. Reduction of crop yields in spite of proper method of irrigation,
ii. Early maturity of crops,
iii. Formation of white deposits on the soil surface,
iv. Formation of swampy area and
v. Continuous high water levels in the wells of surrounding areas.

Water logging is the rise in water table which may happen due to the following causes.

Over irrigation

When the option for an intensive irrigation is adopted, then there will be maximum irrigable area resulting in heavy percolation due to lack of control over the system and causes subsequent rise of water table. For this reason to avoid water logging an option for extensive irrigation needs to suppress that of intensive irrigation.

Seepage of water from adjoining high lands

Water from the adjoining highlands may seep into the subsoil of the affected land and may raise the water table.

Seepage of water through the canal

Water may seep through the bed and sides of the adjoining unlined canals, reservoirs, etc situated at higher level than the affected land resulting in high water table. This seepage is excessive when soil of the site of canals is very pervious.

Impervious construction

Water seeping below the soil moves horizontally (i.e. laterally) but may find an impervious obstruction causing the rise of water table on the upstream side of top layers of pervious soils. In such cases water seeping through the pervious soils is not able to go deep and hence quickly resulting in high water table.

Inadequate natural drainage

Soils having less permeable stratum (such as clay) below the top layers of pervious soils are not able to drain the water deep into the ground and hence resulting in high water level in the affected soils.

Inadequate surface drainage

Storm water falling over the land surface and the excess irrigation water cause flooding of the land. If proper drainage is not provided, the prolonged flooding constantly percolates and raises the level of underground reservoir. Excessive rainfall may create temporary water logging and in the absence of good drainage, it may lead to continued water logging. Obliteration of natural drainage, flat or irregular topography and obstruction of natural surface drainage may enhance the chances of water logging and hence need higher attention.

2.5 Irrigation agronomy

Analysis of the project and investigation of existing agricultural system is required to identify potential crops which can grow in the area. In crop planning for irrigation, it is advisable to first identify all types of potential crops which can possibly grow in the project area (from climate, soil, and environmental aspects) to make a wide crop basket. Environmental requirement of crops are given in several literatures. However, there is the best range of climate, soil and other environmental and socio-economic condition for each crop to render an optimum yield. The checklist (crop basket) has to literally give all ranges of possible groups of crops. After long list of suitable crops for the area have been prepared, it becomes clear that some crops do not warrant passing the next step. The reasons for rejection of the crops have to be briefly given to help the subsequent planners to easily grasp the ideas instead of wasting time investigating the situation.

2.5.1 Farming system

Traditional agriculture has been accustomed with the local agro-climate, physiography, land and soil characters through years and years of farming practice. The farming practice has been subjected to continuous changes and improvements until they have come to be sustainable with an environmental system as it presently exists. Existing farming system reflects: cultural conditions of the local inhabitants, past and present agro climatic complexity of an area, socio- economic status, land resource potentials, constraints encountered including moisture deficiency and/ or surplus. The irrigation agronomist has to identify the major farming subsystems and investigate their characteristics.

The agronomist should review existing agronomic practices as a database for recommendation of the best ones for the irrigation scheme based on the input level and adoption rate of the technologies by the beneficiaries. These are: removal of crop stubbles and residues, land preparation, seed bed preparation, planting methods and date of planting, transplanting (if any especially for horticultural crops), thinning and pruning, irrigation, application of fertilizer and manure, weeding time and method of weeding, cultivation, disease and pest control, guarding (against wildlife and domestic animals such as, birds, monkey, apes, wild pig, porcupines etc. which devastate the crop), crop rotation and cover crops, harvesting, threshing and winnowing, transport, storage (types of storage facilities used, storage capacity, storage disease and pests including cares to be taken), marketing and prices. Note that the amount and cost of agricultural inputs and cost of agronomic practices including land area and taxes form a basis for calculation of crop budget.

An analysis of land use/land cover offers potentials and constraints in that particular unit of land. Over all the type and extent of natural land cover is an indicative of the variability or uniformity of the environment. In cultivated areas the low levels of land use or low cropping intensities reflect exclusion of unsuitable areas, unless used for grazing and other purposes. Tradition in land use is largely the result of accumulated and integrated practical experience of past years and past generations transferred in harmony with the natural environment specifically agro climate. Experiences of land use therefore always play an important role in land *resource planning and management*. The traditions in agricultural land use are extremely useful means of transferring knowledge and experience through successive generations of farmers. Making use of these long years of land use practice in irrigation planning is important for an agronomist in identification of crops and formulation of proposed agricultural development plan.

2.5.2 Cropping pattern and criteria for selection of crops

Having got a basket of crops on the desk, the next noble stage is selection of best crops and establishing cropping patterns for the proposed irrigation project. The choice of crops and cropping pattern for a proposed irrigation project depends on three major areas: Physical, socio-economic and policy and strategies. Once crops have been selected one or more cropping patterns must be proposed. If conditions are markedly different in different parts of the project area, the proposal of more than one cropping pattern may be justified. The cropping pattern has to be divided into dry season and wet season in areas where there exists marked rainfall. All cropping pattern may be for irrigation other may be a combination of irrigation on one part of the project and improved rain fed cropping on another.

A cropping pattern shows what crops are grown, cropping intensity and percentage of each crop grown, when it is planted and when it is harvested. It is convenient to use a diagram or bar chart to represent the proposed cropping program. In this way it is possible to indicate the total growing period and the length of each activities including planting and harvesting. In order to plan the cropping pattern diagram the following information is required. Crop types, date of planting, end date of planting, the total area planted and the crop growth duration. Realizing the importance of crop selection and cropping pattern in determining the fate of that particular irrigation project due emphasis should be given in discussing the criteria‘s briefly as follows.

Climate

As discussed under the preceding section, climate affects the type of crops to be grown. Uncontrolled climatic variations such as temperature, sunshine hours, and the like are mainly determining the type of crops to be grown. Each crop has a range of climatic requirements and has to be correlated with climatic data of the project area.

Availability of water both in quantity and quality

In a general term water is an abundant resource in Ethiopia. The limitation arises when the availability of water is determined in terms of quantity, quality and variability in time and space. Even though there is no overall deficiency of water in the country, the available water is not found in its optimum economic and technical places for irrigation abstraction. The presence of potential irrigable land and water in most of the places are not complimented to each other thus influencing the type of crops to be grown. There is scanty data on quality of water for irrigation and need to be checked inline with the crop tolerance.

Type and method of irrigation

Decisions on the type and method of irrigation and water management require a multidisciplinary data from water resources, soil, socio-economic and institutional capacity. However the type and methods of irrigation influences the type of crops to be grown. For example, the cropping pattern for wider surface irrigation is not the same as under sprinkler or drip owing to the level of technologies.

Crop characteristics and growing pattern

The main physical element determining crop growth and production in Ethiopia is considered to be the supply of sufficient moisture required by the plant at its critical growth stages. The critical growth stages at which optimum moisture is required are the crop development and flowering stages.Perennial crops need adequate moisture to meet the physiological and evapotranspiration requirement throughout the year if production is expected. The major source of water for agriculture in Ethiopia is rainfall. The amount, intensity, distribution and variability of rainfall determine the type and level of crop production. The occurrence of the rainfall pattern has given rise to four main types of crop growing pattern: Perennial, annual, biannual and pasture cropping regime (ESRDF, 1997). The crop characteristics and growing pattern affects cropping pattern and intensity to fit in.

Cropping intensity

The main objective of irrigation is to increase production and raise the income level of a family. Where practical it is desirable for the cropping intensity to approach 200%. In most cases it is not achievable. Cropping intensity is a major factor. It is often preferable to aim at a cropping intensity of around 100-120% under minimum management input, 120-150% for medium input, 150-180% for high management input and 180-200% under intensive commercial management for irrigated agriculture (MoWR,2002). Achieving these different levels of cropping intensities require selection of short, medium or long growing varieties, accordingly.

Soil type and characteristics

The plant roots supply water and nutrients from the soil to the growing parts of plants. Soil types and their physical, chemical, biological properties influence the choice of crops. Any adverse soil characteristics impair the growth and thereby reduce yield of the crop. Most of the crops generally require good physical and chemical conditions of soils. However, there is considerable variation in their tolerance limits. Crops like pulses, vegetables, maize etc. are comparatively more sensitive and require well-drained soils having fine tilth. On the other hand, crops like cotton, barley, wheat, sugar cane, sorghum, rice, soybean, date palm, sugar beet, spinach etc. are more tolerant to salinity. Each crop has its own requirements of soil type and soil characteristics.

Availability of agricultural inputs

Currently the productivity of crops in Ethiopia is below the potential under both rainfall and irrigation. The major reason is the low level of input used by farmers and its availability. Extension packages have shown that many folds increase the success and productivity of crops per unit area by using modern inputs. Hence farmers prefer to grow the type of crops and cropping pattern for which timely provision and availability of inputs such as fertilizer, improved seed, chemical etc are easily accessible provided they can afford to buy the inputs and bear the risk of crop failure, incl. loss of inputs and when there is crop failure from natural calamities they are forced to sell their animals to pay the credits for the purchased inputs which is the sad aspect of farmers in the country.

Conflict over upstream and downstream water use

In areas where there is water use for irrigation, human and livestock and for other purposes both in the upstream and downstream, the conflict over water definitely influences the type of crops to be grown and cropping intensity.

Possibility for crop rotation

Adoption of a varied mix of crops within a systematic crop rotation is essential for maintaining stable yield levels. This may not be necessary in early stages of the project but it is imperative in subsequent stages to incorporate crops belonging to different families so as to neutralize the effect of infestation by soil borne diseases.

Land tenure system

The ultimate ownership of land is vested upon the government and the cultivators enjoy usufruct rights over the land that has been given to him/her. The land reform policy has however, made a provision for individual farmers to lease and pass it on by inheritance to their successors. The frequent redistribution system not only results in land fragmentation but also develops lack of confidence of ownership which may lead to improper use of land and influences the crop types and cropping pattern under irrigation. For example, farmers may be reluctant to grow perennial crops like citrus instead prefer high value short season crops.

Local and international market prospects for the produce

The prospects for local and international market for the proposed crops have to be studied in detail by the project socio-economist and at large by the market expert and given back to the agronomist.

Dietary habit and nutritional requirement of the local people

There is a different dietary habit in different part of the country. In central part and north-western part of the country "teff" constitutes the major diet where as in other parts of the country barely, maize, sorghum, wheat, pulse and other crops are the staple food. The selection of crops and cropping pattern in different irrigation projects is influenced accordingly.

Food demand and food sufficiency vis-à-vis food security

The principal objective of developing irrigation is to establish sustainable food self-sufficiency. In arid, semi-arid and also in some parts of Dega and Woina Dega areas recurrent drought has created food deficit. Even during years of ample rainfall some areas are still suffering from food deficit due to erratic distribution. Hence the types of crops and cropping pattern have to fulfill increased production of food and cash crop from proposed irrigated areas.

Infrastructure condition

There is a serious lack of roads, rail ways and air cargos, transit and shipping line services and port in the country. Air cargo is very expensive. In addition, the distance to major local market centers like Addis Ababa is very far. Therefore crop selection has to take into account especially of perishable products for the presence of both local and international infrastructures especially transport.

Efficient water use

As discussed above irrigation water is scarce in most of the areas. Water use efficiency is a measure of how efficiently a particular crop converts a given amount of water usually one cubic meter into one kilogram of harvested yield; be it grain, leaves, fruits or roots. There is a considerable variation of crops in using water efficiently. Crops like maize, vegetables, fruits, are highly efficient in using water and warrant irrigation whereas crops like sunflower and wheat are among the poorest.

Better land management

The types of crops and cropping pattern may determine the need for better land management. For example, in water logged and seasonal marshy areas crops like rice are preferred. In saline prone areas, highly salt tolerant crops have to constitute the cropping pattern despite any need for other crops.

2.5.3 Agro climatic analysis of the irrigation project area

Climate is a major determinant of agricultural development. For analysis of agro-climate in irrigation development planning, data from class ‘A’ Meteorological Station in the project area or nearby station is required. Because of climatic limitation (especially RF) crop production is confined in the high land areas of Ethiopia more than 1500 masl. The low land which constitutes more than half of the area in the country is not yet potentially utilized particularly the eastern part of the country. The analysis of climatic stations in project area helps us to justify the need and planning of irrigation. The following agro climatic parameters have to be collected and analyzed in collaboration with project agro-meteorologist or hydrologist in irrigation study and design.

Length of growing period

Length of growing period (LGP) concept is one method of assessing rainfall-potential evapotranspiration relationships that define the period in which agricultural production is possible from the point of view of moisture availability in the absence of temperature limitations.

Potential evapotranspiration

Potential evapotranspiration (PET) is used to compute the maximum water transpired and evaporated from the plants. Values of PET help us to identify crop water and irrigation requirements

Atmospheric and soil temperature

Temperature has significant impact on the productivity of crops. Besides the effect of temperature is reflected on evapotranspiration and physiological process of the crops which incurs moisture consumption. Day and night temperature, mean daily, monthly and annual temperature, seasonal temperature has to be analyzed. Thermal zones and crop temperature requirement have to be identified to establish irrigation and crop water management. Soil temperature has to be measured at different depths. Soil temperature is an indicative of soil temperature regime and rooting microenvironment.

Dependable and rainfall probability

Mean daily, monthly and annual rainfall has to be calculated for irrigation planning especially for crop water requirement. The amount of water that is available for agriculture is primarily determined by the amount of dependable rainfall that reaches the surface. Dependable rainfall is usually taken as 80 % and depends on site conditions. The probability of the occurrence of rainfall for each month and season has to be estimated.

Annual rainfall coefficient of variation

Understanding the year-to-year variation is very important not only for crop production but also for planning in agricultural development and hydrological management. Coefficient of variation provides a measure of year-to-year variation. However, some times the applicability of this technique is limited if a given area is dominated by clearly defined cycles and since irrigation requirements are to a large extent crop-related as costs are involved. The fact is that the higher the value of the crop, the higher the requirement, irrespective of rainfall regime.

Generally rainfall variability especially if it is high (CV > 30%) indicates that the annual rainfall pattern is not dependent and is highly variable. These areas are vulnerable to drought. Hence perennial irrigation is required. In areas with CV 20-30%, rainfall is moderately variable. Hence supplementary irrigation is required to complement rain. In areas with CV < 20%, rainfall is less variable (MoWR, 2002).

Sunshine hours and radiation

Daily length/ sunshine hours and radiation are very important in photosynthetic plant growth and estimation of crop water requirement. Radiation data is mainly important in calculating crop water requirement using radiation method. The irrigation agronomist has to analyze daily, monthly, seasonal and annual mean of sunshine hours and radiation to investigate their effect on selected crops.

Wind speed and direction

Wind speed and direction are useful in crop irrigation requirement and crop productivity. Both maximum and minimum wind speed is significant in crop performance especially in late development stage.

Atmospheric humidity

Relative humidity with other climatic parameters is used mainly to estimate PET. Moreover relative humidity has significant effect on crop productivity. The irrigation agronomist has to analyze monthly and annual mean relative humidity (MRH) and investigate their effect on selected crops.

2.5.4 Soil-water-crop relationship

Having selected crops and formulated cropping pattern (as discussed in the preceding sections), the next crucial step is to investigate soil-water-crop relationship for each selected crop. For irrigation planning, it is very important to know soil-water-crop relationships. Most of the time this part is overlooked or unknowingly ignored by the agronomist and the irrigation engineer in which otherwise irrigation planning is based on conventional system. For example plant evapotranspiration and soil water extraction processes require an understanding of the driving forces and principles involved.

These principles include evapotranspiration, soil moisture retention and soil moisture movement in conjunction with plant root growth and characteristics of moisture extraction and adsorption. In agricultural development especially in irrigated agriculture, it helps to formulate and plan crop-water and yield optimization. In all cases, investigation of crop physiology and soil characteristics on one hand and their joint reaction in the presence of moisture and application of artificial water (irrigation) on the other hand is believed to be an objective approach.

Factors influencing soil-water and crop relationship

The factors affecting the soil-water relations of plants and thus their growth and yield response may be grouped into the following.

i. Soil factors such as soil moisture content, texture, structure, density, salinity, fertility, aeration, soil temperature, compaction, infiltration, permeability and drainage.
ii. Plant factors such as type of crop, planting density and depth of rooting, rate of root growth, aerodynamic roughness of the crop, drought tolerance and variety effects.
iii. Climate factors such as sunshine, temperature, humidity, and rainfall.
iv. Miscellaneous factors such as soil volume, soil and crop management etc.

These factors have to be analyzed in irrigation project planning especially in crop selection and cropping pattern, estimation of crop water requirement, recommendation of cropping practices and yield build-up.

Evapotranspiration

Evapotranspiration is used to define the sum of transport of water from the plant surface as transpiration and transport of water vapor from the soil surface as evaporation. The transpiration and evaporation components are driven by vapor pressure gradients between leaf or soil surfaces and surrounding air. As the vapor pressure deficit increases, the potential for evaporation and transpiration increase. Convective and forced movement of air (wind) enables continual exchange of air, heat and vapor at evaporative surfaces. Under conditions of adequate air movement, the vapor pressure deficit is maintained at a maximum value representative of the air mass above the crop and soil surface. Net incoming energy incident to plant canopy is converted into sensible heat causing a warming of air and evaporated.

The proportions of transpiration and evaporation are determined by leaf area and roughness of the plant canopy, dryness of the soil surface, moisture levels with in the soil profile, and soil moisture extraction capacities of the plant. Under conditions of a dry soil surface, micro-scale advection of sensible heat and increased vapor pressure deficit from the soil surface to the nearby crop canopy can increase the transpiration component of ET proportional to the decrease in soil evaporation.

Water uptake

An important variable governing water uptake is the physical distribution of the root system. Distribution of plant roots have been described in a number of ways such as length of roots per unit volume of soil, mass of roots per unit volume of soil, or as an effective depth of soil for moisture withdrawal. The distribution of roots with depth does affect the pattern of water depletion within the soil profile. Effective rooting depths of plants are dependent up on plant age, variety, soil texture, structure and layering and soil water management. The root density and penetration depends on soil strength and root tip size relative to soil pore size and structure. Compacted hard layers reduce root elongation unless pore spaces are larger than root tip size which varies with plant type. Studies of root distributions and activities indicate that root activity and water depletion is greatest at shallow depths where root densities are greatest provided the soil water potential is uniform through out the soil profile.

As lower potentials develop in the upper portion of the root zone due to moisture depletion from greater root activity, increasingly greater proportions of transpired water are removed from depths where root densities and activities are lower because water flux per area of root must increase as root density or activity decreases. The transpiration demand of a plant is fulfilled only as long as values of potential gradients and hydraulic conductivity of soil contacted by roots remain great enough to effect sufficient water flow. In order for plants to use water until the soil-water potential approaches the maximum potential found within the plant, the hydraulic conductivity of soils must remain sufficiently high and root distributions sufficiently dense so that these parameters do not become limiting under these conditions.

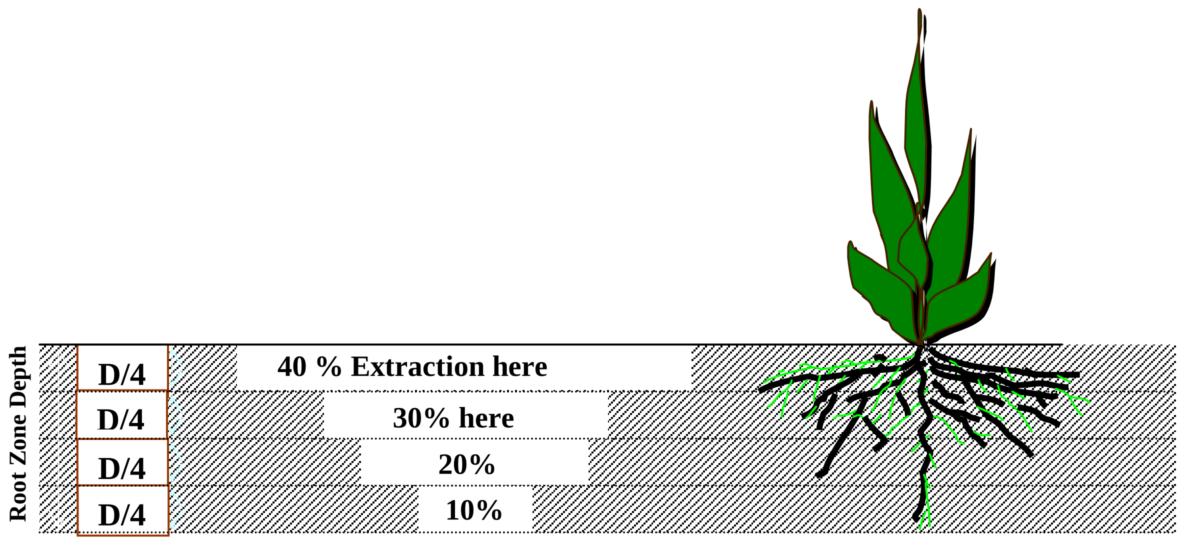


Figure 6 **Average moisture extraction patterns in a soil without restrictive layers and with a constant supply of available moisture, USDA 1964 and Prinz 2007**

Field capacity and permanent wilting point

Field capacity is the soil moisture content after drainage of gravitational water has become very slow and the moisture content has become relatively stable. At field capacity the large pores are filled with air, the micro pores are filled with water and any further drainage is slow. The field capacity is the upper limit of available moisture range in soil moisture and plant relations.

Permanent wilting point is the soil moisture content at which plants can no longer obtain enough moisture content to meet transpiration requirements and remain wilted unless water is added to the soil. Both field capacity and permanent wilting point are measurements in laboratory from undisturbed soil sample.

Available water capacity

Available water is soil moisture between field capacity and permanent wilting point. It is the moisture available for plant use. In general fine textured soils have a wide range of water between field capacity and permanent wilting point than coarse textured soils. Available water is calculated from FC, PWP and bulk density of the soil.

It needs to be emphasized that the crop physiology and soil-water relation ship should be clearly known before planning of cropping pattern, recommendation of inputs and agronomic practices and estimation of yield and crop water requirement. The failures in irrigation projects in most cases are attributed to these natural processes and the action taken to change by introducing different inputs like water, seeds, chemicals etc. A soil-water-crop relationship is a basis to estimate crop water requirement and irrigation water requirement.

2.5.5 Crop water requirement

Having analyzed agro climatic parameters of the project area in section 2.5.3, established cropping pattern/intensity in section 2.5.2, investigation of soil-water-plant relationship for each crop (section 2.5.4), the next core of the whole irrigation development planning and management is estimation of reference (crop) water requirement, crop water requirement, and project irrigation requirement. The water requirement of a crop depends on the climate. Under the same climatic conditions different crops require different amounts of water and the quantities of water used by a particular crop varies with its stage of growth. Initially during seeding, sprouting and early growth a crop uses water relatively at a slow rate. The rate will increase with growth of crop reaching the maximum in most crops as it approaches flowering and then decline towards maturity.

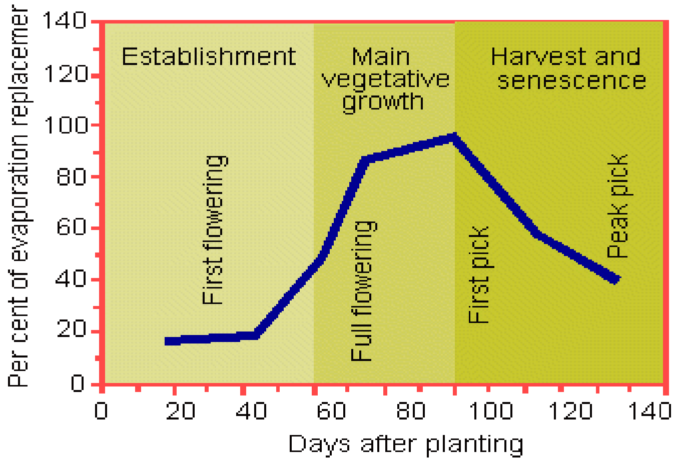


Figure 7 Change in crop water requirement with the stage of growth, Agricultural Western Austria 1990

Reference (Crop) Evapotranspiration

Evapotranspiration or consumptive use is the sum of the amount of water evaporated from the soil and the amount of water transpired by the crop. It is the total movement of water vapor into the air from land which supports plant life including transpiration from plants and evaporation from water or plant surfaces. ETo is defined as the rate of evaporation from an extensive surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and with no shortage of water (Prinz, 2007). The primary factor controlling evapotranspiration and ETo is the thermal energy of radiation reaching the surface of the earth. However, solar radiation, air and soil temperature, humidity, vapor pressure, wind velocity and specific crop and variety are all interrelated factors in evapotranspiration process.

Methods of estimating reference (Crop) water requirement

Based on meteorological data available select a prediction method to calculate reference crop evapotranspiration, ETo. If a complete set of meteorological data is available the choice of a method should be based on the required level of accuracy in predicting ETo. There are six major methods to estimate reference crop evapotranspiration (ETo). The Blaney-Criddley, Radiation, Pan Evaporation, Christiansen, Hargreaves, and Penman methods.

Table 2 Comparison of data requirement for estimation of crop water requirement, Prinz 2007

Method	Temperature	Humidity	Wind speed	Sun shine	Radiation	Evaporation	Environment
Blaney-Criddley	*	**0**	**0**	**0**	**-**	**-**	**0**
Radiation	*	**0**	**0**	*	**(*)**	**-**	**0**
Penman	*	*	*	*	**(*)**	**-**	**0**
Pan Evaporation	**-**	**0**	**0**	**-**	**-**	*	*
Christiansen	*	**0**	**0**	**0**	**0**	**0**	**0**
Hargreaves	*	**(*)**	**(*)**	**(*)**	**0**	**0**	**0**

* **Measured data** **0 Estimated data** **(*) If available, but not essential**

The FAO Penman-Monteith method is recommended by FAO and WMO as the sole method for determining ETo. The method has been selected as it closely approximates grass ETo at the location evaluated, is physically based and explicitly incorporates both physiological and aerodynamic parameters. Moreover, procedures have been developed for estimating missing climatic parameters. On the use and selection of meteorological station (data) the nearest is recommended but if not available it is recommended to use other stations having similar elevation (altitude) and landform (topography). A maximum of 150 meter elevation difference can be used. Where no wind data are available with in the project area a value of 2 m/s can be used as a temporary estimate (MoWR, 2002). This value is the average over 2000 weather stations around the Globe. When solar radiation data, relative humidity data and wind speed data are missing Hargreaves' method is recommended

Crop Evapotranspiration (ETc)

Crop evapotranspiration ETc is calculated by multiplying the reference (crop) evapotranspiration ETo by a crop coefficient, Kc.

$$ETc = KcETo \qquad (4)$$

Where ETc = Crop evapotranspiration (mm/day)

K_C = Crop coefficient (dimensionless)

ETo = Reference (crop) Evapotranspiration (mm/day)

Most of the effects of the various weather conditions are incorporated in to the ETo estimate. Therefore as ETo represents an index of climatic demand, K_C various predominately with the specific crop characteristics and only to a limited extent with climate.

IRRIGATION WATER REQUIREMENT

Net irrigation requirement (N.I.R)

It is the depth of water needed to bring the soil moisture level in the effective root zone to field capacity from the soil moisture content. For planning irrigation all aspects of crop water requirements have to be considered including growing period, cultivation program for each crop, and any possible contribution from rainfall and the percolation loss from the soil (mm/day). While considering rainfall we must take account of effective rainfall and hence,

$$NIR = ETc - \mathrm{Re} \qquad (5)$$

Where NIR is net irrigation requirement

ETc is crop evapotranspiration

Re is effective rainfall

Effective rainfall (Re)

It is that portion of the rainfall falling during the growing period of the crop which is available to meet the consumptive water need or the evapotranspiration requirement of the crop. It does not include precipitation loss due to deep percolation below the root zone.

Percolation

It is downward movement of water through saturated or semi-saturated soil in response to the force of gravity. Percolation rate is synonymous to infiltration rate. It varies from soil to soil and may be classified as sandy (upland), loamy (midland) and clayey (low land). This rate varies from 5 mm/day upland, 3.5 mm/day for mid land and 1.5 to 2 mm/day for low land (ESRDF, 1997). The rate of percolation in mm/day is to be determined by field tests.

Field irrigation requirement (F.I.R)

It is the net irrigation requirement plus loss in water application. Due to field application losses, not all the water delivered to the field is available to the plants. Therefore an efficiency factor is considered. The N.I.R. divided by efficiency coefficient of the water application gives us the amount of water that actually has to be delivered to the field (field irrigation requirement). Field irrigation requirement (FIR) is equal to net irrigation requirement (N.I.R) divided by efficiency coefficient of the water application in the field. The field efficiency generally varies depending upon method of irrigation and type of crop.

Irrigation efficiency

It is the percentage of applied irrigation water stored in the soil and available for consumptive use by the crop. When the water is measured at its entry to a farm it is called farm irrigation efficiency; when measured at the field it is known as field irrigation efficiency and if measured at the point of diversion it is called project efficiency.

Gross irrigation requirement

It is the net irrigation requirement plus water application losses in the conveyance system due to seepage, evaporation etc. This can be determined at the outlet head or canal head regulator for calculating the design discharge capacity of the main off-taking canal. The losses generally depend upon whether the canal network is lined or unlined, the surface area and the ground percolation.

Water stress period of crops

Each crop has a different water stress period depending mainly on the climate and soil type. Some crops are sensitive to the water stress at germination period while others at development or flowering period. The water stress period for each crop has to be obtained through research. At the absence of research data an agronomist is advised to use cautiously standard publication such as FAO. Knowledge of water stress period helps in fixing irrigation requirement and scheduling.

Irrigation Scheduling

The amount of water that should be applied for any given irrigation depends on the stage of crop growth, the depth of the rooting zone, and the field capacity of the soil. Thus the amount of water applied varies according to the stage of growth. Regarding soils, under the same climatic conditions, soils with low field capacities (sandy and sandy loam soils) require less quantities per application but more frequently than soils with high field capacities (silt loam and clay loam soils).

Pulses, food grains (maize) need frequent irrigation but slightly longer than the vegetables. Water is normally available to the plant at moisture contents between field capacity and permanent wilting point. The difference between the soil moisture content at field capacity (FC) and the soil moisture content at permanent wilting point (PWP) is described as the total available soil water (Doorenbos and Pruitt, 1977).

To calculate how much water can be stored in a particular soil type and depth and made available for use by the crop, it is necessary to consider the depth of soil from which the plant roots can draw water which is the rooting depth, D. When the soil is at field capacity the plant can extract water easily to maintain the maximum rate of evaporation. This is the freely available soil moisture and is defined as the fraction (p) to which the total available soil moisture can be depleted without causing the evapotranspiration to drop. The depth of freely available soil moisture in a soil with rooting depth (D) is given by *P x Sa x D.* The balance of the total available water is called not freely available water with the depth of (l – p x Sa x D) (Doorenbos and Pruitt, 1977)

$$RAM = P \times Sa \times D \qquad (6)$$

Where RAM is readily available moisture
Sa is available water in the root zone (mm)
D is effective rooting depth
P is management allowed depletion (fraction of the total available soil water)

Management induced environmental stress

Many agricultural crops are intentionally water stressed during specific crop growth periods to encourage particular crop characteristics. The water stress is initiated by withholding or by reducing irrigations. In situations where this type of cultural management is practiced, the Kc should be reduced to account for the reduction in evapotranspiration. Environmental stress from soil water shortage, low soil fertility, or soil salinity can cause some types of plants to accelerate their reproductive cycle. In these situations, the length of the growing season may be shortened particularly the mid-season period. Stress during the development period may increase the length of that period. Therefore, the length of the midseason and perhaps the lengths of the development and late seasons may need to be adjusted for environmentally stressed or damaged vegetation. Local research and observation is critical to identify the magnitudes and extent of these adjustments (Richard et al., 1998).

2.5.6 Irrigated farm input and support services

Having selected the best crops and adopting a combination of alternative cropping pattern as discussed in the preceding sections, the next important step for the irrigation agronomist is to identify irrigated farming input and support service requirements. Fast growth in agricultural production can be achieved through the use of required inputs such as high quality seeds, fertilizer, other agricultural chemicals, machinery and implements. The use of expensive inputs like fertilizer, machinery and chemicals are effective and should be profitable when irrigation water is used.

Seeds

The role of improved seeds when used together with other complementary inputs and appropriate practices in increasing yield has been an established fact. Seed is one of the most critical inputs in increasing productivity. The uses of expensive inputs like fertilizers and other chemicals, machinery, irrigation water and power are effective and profitable when super quality seeds are used (MoWR, 2002). Improved seeds and rate of seeding have to be recommended for each proposed crop. Ethiopian seed enterprise and other private seed companies are engaged in seed multiplication and distribution.

Fertilizer

To benefit from increased crop yield, fertilizer has to be recommended with improved seeds. Fertilizer is imported by private and government agencies and distributed to farmers through Regional Agricultural Departments. Type of fertilizer and application rate has to be recommended. Fertilizer application should be combined with manure application or other methods to increase soil organic matter to create a high cation exchange capacity (CEC).

Chemicals

Crop protection chemicals are not yet popular despite the damage of pests and diseases both in the field and post harvest. The major pests are diseases, birds, insects (both field and post harvest) and weeds. According to research assessments, insect pests do most of the damage of up to 15-20% as compared to disease and weeds. All together the loss is more than 30% (ESRDF, 1997). On-farm crop protection from insects and weeds can be effected through the use of chemicals. At any case the irrigation agronomist has to assess the type of chemical available and recommend the best one to his farm based on the type of pests. Integrated Pest Control should be practiced and non-toxic remedies preferred.

Labor and draught power requirement

Farmers most of the time use family labor for their farm activities. During peak season, they are forced to hire labor. Hence availability of labor in irrigation during peak time is important. To plan labor, knowing total requirement and timeliness is necessary. The same is true for draught animal requirement. The estimated average draught animal requirement for irrigated cropping in the peasant sector is about 18-20 pair days/ha (ORDA, 1999). Most of this would be required for land preparation with some additional requirement for inter cultivation and transport of harvest. Labor and draught animal requirement and typical schedule of the requirement has to be estimated inline with cropping calendar and farm management practices.

2.5.7 Agronomic practices for selected crops grown under irrigation

Agronomic Practices

Having formulated the irrigated agricultural development, the next step is to identify crop requirements and recommend agronomic practices. The agronomist shall review existing agronomic practices as a basis and recommend the best for the irrigation scheme based on the input level and adoption rate of the technologies. The following agricultural practices (but not limited to) can be recommended and each has to be briefly discussed as guidance for the users.

Removal of crop stubbles and residues: Crop residues have to be collected in selected places within a farm immediately after harvest. Decomposition of crop residues by exposing to heat and moisture to return to the farm is highly advised.

Land preparation: Oxen, horses, manual and in rare cases machinery. The number of times of cultivation should be given for each crop. Cultivation by oxen, manual or machinery is made to reduce weed population and pulverize soil

Thinning and pruning is practiced to reduce competition for nutrient, light and moisture.

Irrigation: Pre-irrigation may be preferred for some soil types.

Application of fertilizer and/or manure application: Farmyard manure and compost application is preferable, as the capacity of farmers to pay for chemical fertilizers is limited.

Weeding: Time and method of weeding need to be indicated

Disease and pest control: Cultural, biological and chemical spraying methods and timing have to be explained considering economic threshold. Integrated pest control is preferable

Crop rotation and cover crops: Recommended crop rotation and cover crops to maintain fertility anti disease/pests control have to be explored.

Figure 8 Family harvesting wheat from Kulanti IP

2.5.8 Estimation of agricultural production and yield build-up

Having established cropping pattern and recommended irrigated farm inputs (section 2.5.6 above), the next step in irrigation development planning is estimation of agricultural production and yield build-up. The main output of an irrigation project is increased crop production. Based on the data obtained from different sources, the achievable yield and the possible increase in yield over the project life for each crop has to be estimated. The total production and incremental production helps in calculation of financial flow by economists.

Yield build-up

The yield build up period is related to the rate of implementation of the proposed and recommended technologies and management system. It also depends on the rate of adoption of the proposed management techniques and modern agricultural inputs. However, some constraints such as lack of timeliness and inadequacy in the supply of modern inputs, shortage of draught power, lack of credit to buy the inputs etc., may impede the rate of adoption.

Basis for yield estimation and build up

Existing crop yield data has to be collected from different sources. These are Zonal Agricultural Departments, Planning Departments, Regional Bureau of Agriculture, pervious studies, and research results. Yield estimation for proposed irrigation project can be based on the following

i. Yields obtained from on-farm and adaptive research
ii. The anticipated input and management level.
iii. Regional and national average yields under irrigation.
iv. Yield obtained in other similar countries with a similar socio-economic and agro-ecological environment.

2.5.9 Irrigation extension and training

The need for irrigation extension

The measure of success of irrigation is its ability to meet its objectives and targets. Extension supports to achieve the irrigation project by

i. Increasing the agricultural returns from irrigated agriculture and thereby increase living standard and alleviate poverty.
ii. Improving the farmers' capacity to develop agricultural production so that schemes achieve their economic potential.

The achievement of successful schemes and viable projects that meet the desire of the beneficiaries can then be realized and should not end on completion of the irrigation infrastructure. For the farmers to be able to increase the total value of their output, they need not only regular access to markets, credit and on farm inputs but also exposure to technological improvements and an opportunity to learn new skills. It is necessary to ensure that the intensity of the extension input developed remains especially high during the first years of cropping as this is the time when farmers need to adapt to the considerable changes in the cropping pattern, increasing intensity and agricultural practices that can be expected with the introduction of irrigated agriculture for the first time. Therefore, it is important that the extension services are in place and prepared prior to the onset of the irrigation.

Diagnostic visits

Regular visits by extension agents need to be carried out at least fortnightly or monthly (as need arises) on a predetermined date agreed with the farmers. The purpose of the visit is to diagnose or identify farmers' current problem. If the irrigation development agent is unable to solve, he/she needs to refer to the appropriate technical specialist at district or zonal level. For example, if the problem is of pests and disease attack and where diagnosis is uncertain research staff and university academicians can be requested for assistance.

On farm practical and demonstration plots

The purpose of these plots as the name suggests is for farmers to practice the skills relevant to a particular crop or land practice and observe the results. Plots have to be established with cooperating farmers on a portion of the land that they are themselves planting the same crop. The advantage of this is farmers will be aware that the plot has been farmer managed and that any benefit is therefore capable of being replicated on their own farms.

Prior to setting up the demonstration plot plan has to be drawn up. This describes the plot objective, includes a sketch and details the activities and key observations that are to be carried out. Results are recorded and cost benefits calculated. Tasks on the plots have to be demonstrated where possible with farmer practice. The observable and quantifiable results have to be available to other farmers physically and with photographs.

Pilot trials

Any agronomic, soil, irrigation and drainage problem anticipated during feasibility study and detail design stage is tested and resolved prior to operation of the project. If there is research station in the project area, there is a possibility of integrating the pilot issues into the existing research program.

Skill transfer demonstrations

Irrigation development agents (IRDA) have to make specific skill demonstrations as a normal course of their work. Skill transfer is then undertaken as needed either as a single planned operation as an ad hoc in the course of an advisory visitor included as part of the program on demonstration and farmer plots. A training officer has to arrange to produce a series of brief skill instruction plans for the commonly needed skills.

Field days

Field days are needed when scheme awareness is required on a particular topic or theme and generally focuses around demonstration plots and successful farmers. The activity may range from modest demonstrations with short technical talks to a campaign with several presenters, audio-visual aids and displays. In certain cases the event may permit the inclusion of some social activities which usually encourage attendance and help foster community spirit. It is also encouraging to prepare an award for merit jobs.

Farmers' meeting

Farmers meetings and open discussion on different development agendas are traditional ways of disseminating extension messages. Information is often exchanged among farmers and among IRDA. Farmers are usually enthusiastic to get on with it the best way they can. This is not appropriate at early time where new practices are being introduced. Farmers' meetings play an important role as a discussion forum for seeking opinions and consensus on programs and future plans, marketing, credit and repayment, farm inputs and provision of services.

Farmers' group visits and farm transect walks

Visits could be arranged when it is of particular advantage for farmers to see and discuss the activities with other farmers or of particular benefit to visit farms, research and field stations.

Study tours

Local and international study tours can be arranged for a group of farmers to enable farmers' learn the new technologies. Some NGOs have started such program and found it successful.

2.6 Watershed management

Watershed is a fundamental unit for water resources management. The term watershed implies a domain or system within boundaries. The watershed domain may be further divided into sub components of smaller watersheds or into sub processes such as overland flow and sediment yield. Watershed management practice involves changes in land use or land management practices including structural and biological measures. Alternatively it refers to the use of the land according to the capability for sustainable resources uses. Watershed management activities involve the following major components.

i. Stabilizing the top soil.
ii. Stabilizing and modify stream flow.
iii. Improving water quality.

Watershed management practices affect upstream and downstream area and usually affect more than one community, institution and administrative units. Implemented watershed management activities yield physical effects (on site, increase productivity downstream, reduce sedimentation, increase water flow during critical periods etc). The key objective of watershed management aims to promote both soil conservation and water resources objectives with upland management strategies that diversify and increase income generation through the production of agricultural and natural resources and need attention in the planning of diversion irrigation systems.

3 Management, operation and maintenance

The optimum use of irrigation water to grow maximum crop per unit of water is an essential requirement of good soil and water resources management. In its absence the conveyance and field application efficiency becomes low resulting in low yields, excessive deep percolation losses and rise in water table, salinity etc. Water management is an integral process of storage, diversion, conveyance, regulation, measurement, distribution, application and removal of excess water and salts. It is not only about water resource, irrigation facilities, water laws, farmers' institutions, procedures of cropping system, but also it is a manifest in how best an organization should develop. And these tools and resources are used to provide optimum irrigated agriculture and improve general ecology which is a contribution of social, agronomic, engineering and economic endeavor. Apart from field management and implementing operational plans, monitoring and evaluation is equally important to consolidate, make and maintain the system functional.

The overall routine management, operation and maintenance are to be looked after by the water users association (WUA) for the small scale irrigation project and project control center (PCC) for medium scale irrigation project. It is quite imperative that different groups amongst the WUA and PCC are formed who will be associated with the different components so as to have in depth knowledge of the functions and utility of the scheme. Without this awareness and know how proper management, operation and maintenance cannot be sustainable and successful. The WUA and PCC need also be given training within the project by arranging workshops and other facilities for field visits to other developed agricultural farms.

The operation and maintenance of the diversion structure, appurtenant works, infrastructures, on farm development and last but not least the drainage system need knowledge, systematic approach, constant vigil and devotion to utilize the services successfully and sustain the scheme for a longer period of time. There are two aspects of irrigation system management: Water Management and Infrastructure Management. Water management involves the following issues:

i. Procedures and methods for flow measurement, operation of the system and farm structures for regulating the flow as per the need with least human intervention and maintaining the drainage system. It also lays out the water distribution system through farm structures that are self operated according to the crop needs.
ii. Methods and procedures for the regular and periodic monitoring of the system and structures.

Infrastructure management includes the main, branch conveyances, the structures, tertiary canal, outlets and drainage system.

i. Procedures and methods for checking and evaluating the desired functions of the hydraulic structures including farm outlets (turnouts).
ii. Methods and procedures for regular and periodic maintenance of the structures and farm outlets.

3.1 Management plan

Irrigation increases crop production but maintaining increased crop production over a long period of time is difficult without proper management. The proper amount of water should be applied to the root zone at proper time. Timing and quantity of irrigation water are related to climate, soil type and stage of growth. Proper management to minimize the supply of irrigation water to meet crop water requirements must be instituted and improved with new lands coming under cultivation. Hence water management is given prime importance to the operation of or to modify existing system to meet new and changing demands.

Water management which forms an essential part of any irrigation project includes head works, conveyance, regulation, measurement, distribution and application of irrigation water to soil as well as drainage of excess water. Improved water management requires implementation of technological solutions with institutional changes for optimum water use restrictions. Water use regulation combined with flow measurement devices is pre-requisite for effective water management. Thus irrigated agriculture is a combination of engineering, agronomic, meteorology, social and economic endeavors involving the farmers with their due importance in the formulation, implementation, operation and maintenance along with their overall association in the management and monitoring of the land and water use.

The systems approach attempt to understand the physical, agronomic and social aspects of operation and subsequently developing an interdisciplinary team consisting of engineers, agronomists, sociologist and the committee members of the WUA. For small scale irrigation projects the beneficiaries (WUA) after gaining experience of the operation and maintenance (O & M) system should gradually take-over but will always remain within the zonal administrative monitoring and evaluating cell which educates the WUA from time to time. Thus they are equipped with the skills required to monitor and evaluate the input and output for achieving optimum efficiency.

To meet the end and achieve optimum land water use, it is very essential to prepare a water distribution network best suited to topography and land classification. This network has to cater for not only to the physical or quantitative parameters but also to take into account the operational system which involves equitable distribution of water to all fields within a fixed time to meet the crop water requirements with least human intervention. Map which shows the layout and specific features need to be prepared at a convenient scale and submitted to the WUA for small scale irrigation project and to the PCC for medium scale irrigation project. The map is used for proper management, operation and maintenance works. To illustrate the functioning of an irrigation canal network it can be compared to a tree.

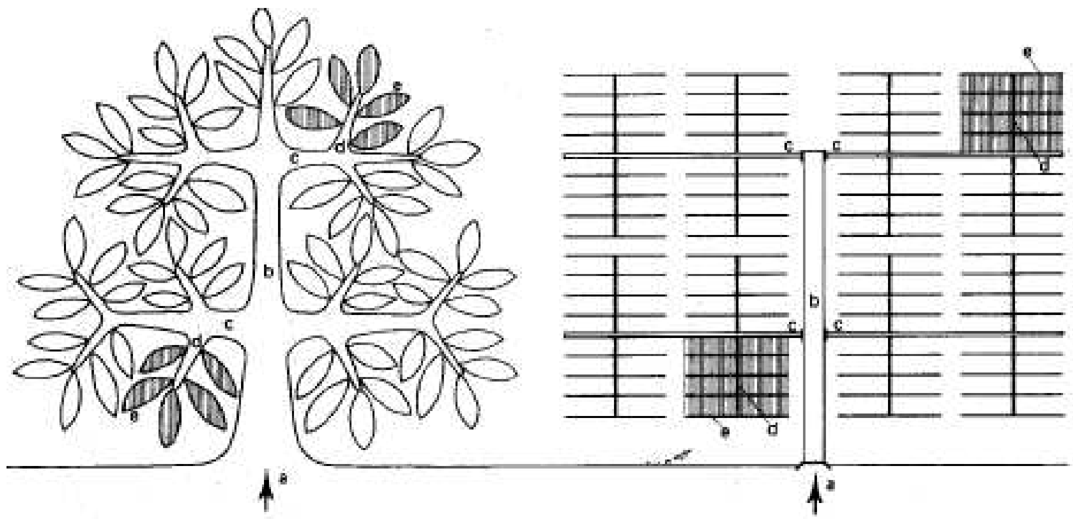


Figure 9 Flow chart showing water conveyance, Bosch et al., 1992

The main stem of a tree taps water from the soil and transports it to the branches. The branches supply the twigs with water and finally it enters into the leaves where it is either used for growth or evaporates. The same can be seen in an irrigation scheme: The main or primary canal (the stem) taps water from the water source which may be a river, a lake, a reservoir or ground water. Water is then distributed by the smaller secondary canals (the branches) to the tertiary canals (the twigs) which are even smaller. From these tertiary canals the water finally enters the fields (the leaves), where it be used to irrigate a crop and evaporate or soak away. The canals are positioned in the field so that use is made of the natural slope and water flows downhill through the canals and enters the fields by gravity.

3.1.1 Irrigation scheduling

The crop water requirement varies at different stages of crop growth. It is maximum during the initial vegetative growth and flowering period, Figure 7. Supply of timely water in the required and requisite quantity is necessary to obtain optimum yield. Both over and under irrigation result in reduction of crop yield and excess water causes water logging, salinity, wastage of the valuable water and unnecessary straining of the system. It is necessary to access the actual weekly crop water requirement in advance considering the *moisture depletion and sustainable crop stress* and prepare a schedule of irrigation i.e. frequency of watering and quantity of water necessary. This depends upon rainfall, crop development, soils, fertilizer, climatic conditions and crop factors.

Consideration of providing supplementary irrigation to rain fed crops, complete dependability of certain crops and life saving aspects of third category of crops are to be made while fixing or altering pre-planned irrigation scheduling. This schedule is made known to all farmers so that they are ready to utilize the water efficiently. The schedule should match the water potential available. Generally this is done at an interval of one week or multiple of weeks to maintain the rotational water supply system.

3.1.2 Water budgeting

The extent of irrigation development in the command depends on the correlation between the crop water need and water potential available. The system being designed on 80% dependable yield, planning is done considering this available dependable yield and the crop water requirements for the selected cropping pattern during the crop year. The crop has to be sustained and developed but due to scanty rainfall the full reservoir level may not be achieved (in case of dams). When the inflow to a diversion structure is found to be less than the assumed yield, the subsequent crop group and the crop water requirement has to be modified/ adjusted according to changed situation of the water availability. Thus water budgeting is needed in optimizing its use for proper crop development. In other words, water application needs to be reassessed every year at the end of rainy season.

Moreover, crop water requirement must be updated every year as more climatic data which contributes to reliability of the estimate are obtained for better resizing of field canals during the maintenance period. This data is also important to optimize pumping hours in pumping irrigation schemes. It is to be observed that undesired withdrawal is not done at any stage to adversely affect the future planned plant and their yields. It is therefore necessary to ascertain and plan for proper operation and sustainability of the scheme considering the available water, irrigation required and available storage for better utilization of available flow in the stream. Once the system has been in operation for a few years, the quantity of water actually available for irrigating the type of crops is actually found out. Thus ultimately the water factor and land factor is known and a permanent system continues and the beneficiary‘s factor is also solved.

The system operation also includes night storage though it is not common practice. This is needed only in a diversion scheme where the storage is created from the flow available during night hours or on closure days as the irrigation is done mostly during daytime. In the night irrigation system also the same operation schedule has to be followed. A regulation arrangement is made at the entry and exit ends of the night storage structure which serves as a balancing pond to meet the crop needs during emergency.

Figure 10 A typical night storage pond, ORDA 2001

3.1.3 Duration of irrigation

It has been observed that though the infrastructure is designed for a continuous flow for 24 hours during a weekly rotational period, many farmers do not recourse to irrigation during night hours. Therefore, they dose the outlets resulting in wastage of water, breaches and cuts in the canal and damages to the structures. Especially in a command area of medium and small scale irrigation project where villagers mostly reside at a distance from their respective holdings night irrigation seems difficult to perform. On the other hand, even if a few farmers may agree for the night irrigation this may not hold good for sensitive crops especially in cold night hours.

3.1.4 Organizational setup

The WUA formed by the beneficiaries have to be associated with the construction /execution of all the components so that they remain acquainted with know how of the functions of the components i.e. their purpose, importance and nature of their proper upkeep and safe functioning during maintenance stages. The groups of persons both semi-skilled and educated have to be acquainted with different components from the beginning which ultimately perform the tasks of basic management, operation and maintenance.

Each farm area should have a farm area leader selected from the users and each block should have tertiary area leaders selected from the tertiary area beneficiaries. There has to be an overall WUA executive managing committee. The functions of the committee are

i. Proper and efficient distribution of water among the beneficiaries.
ii. Maintenance of the irrigation structures.
iii. Collection of different fees from the beneficiaries such as for the purchase of different materials required for maintenance, for payment of the maintenance work that requires skilled manpower and/or water charges.
iv. Proper allocation of water among beneficiaries depending on the proposed cropping pattern for efficient use of water.
v. Form their own rules and regulation.

Farmers having irrigable land in the scheme have to be members of the water users association and be governed by rules and regulation of the association. The users' organization is based on their settlement. It is important to follow the basic framework and build the organization structure on this principle. The first level (element) of the system is neighborhoods. Sub divisions (farmers group) will be based on adjacent farmers utilizing the same primary or secondary or tertiary canal number ranging from 20-30 (ORDA, 1999).

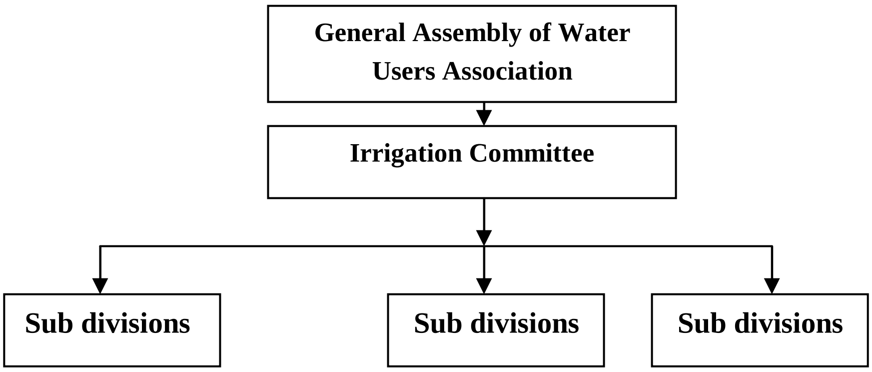


Figure 11 Schematic presentation of water users association at grassroots level, ORDA 1999

Organizational structure by itself would not achieve much unless supported by other process like defining the functions and responsibilities of each unit in the organizational system. Accordingly, the following functions and responsibilities are recommended.
The association has the following administrative body:

a) General assembly
b) Irrigation water users executive managing committee

The general assembly with the presence of every member of the association has the power to give the higher and final decision concerning the association.
i. Has the power to elect, replace, and reject members of the irrigation committee.
ii. Has the responsibility to update or replace the rules and regulation of the association.

iii. Control and regulate the general work plan of the association.

An indicative regulation (bylaws) for members of WUA follows. Rights and obligations of the members are (MoWR, 2002)

i. To elect or to be elected as member of the irrigation water users committee.
ii. Equal right to any matter of the association.
iii. Farmers using water for irrigation are obliged to pay the amount requested to the water committee for stationary or for maintenance purpose.
iv. At any time notifying to the association his/her irrigable land can be given to other person depending on the government policy to lease out, rent, etc.
v. Equal rights on the benefit of the association and water utilization.
vi. In general the water users association is responsible for maintenance of the canal, operation (water distribution), to form their own rules and regulation (full right reserved for the association).
vii. A farmer water right (when to irrigate) is determined by an agreement coming from users of the same group.
viii. Every member of the association guards the canals for their proper utilization of water.

3.1.5 Flow measuring devices

One of the essential requirements for water management is an adequate number of flow control and measurement devices. Without knowing the quantity of water to be managed, there cannot be good water management. Flow measurement structures should be provided at the head work, at the main conveyance, at beginning of each secondary, tertiary and at intermediate points on long secondary and tertiary. All types of farm inlets should be calibrated. By calibrating the farm inlets the amount of water delivered to meet any particular demand can be measured. Besides fixed flow measuring devices, portable devices such as a V-notch can be employed for small flows and current meter for large flows only when situations permit its use (USDA, 2001).

The quality of personnel operating the distribution system is an important factor in the proper management of water at farm level. Provision of trained personnel for operation and maintenance of irrigation system is essential. Attention should be paid to training those working directly and indirectly on the farm distribution and drainage system. The following are the most common flow measuring devices.

Parshall flume

It is installed in the main conveyance system at the head reach. It comprises a converging section at the upstream, a sloping section as “throat section” in the middle and a diverging section on the downstream. Water depth readings are taken on a gauge strip fixed on the “converging” and “diverging” sections. There is no need to have a pond above the flumes as the velocity of approach has little effect on the accuracy of measurement. Discharge through the flumes can occur under either free flow or submerged flow conditions. Where the elevation of the water surface downstream from the flume is high enough to retard the rate of discharge the flow is considered as submerged.

To determine the discharge two scales *Ha* and *Hb* are provided at the upstream and downstream section of the flume.

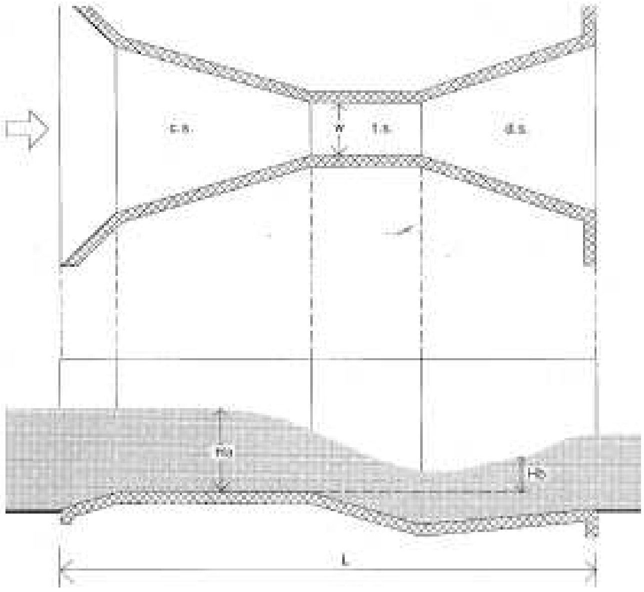


Figure 12 Plan & longitudinal profile of a Parshall flume, Bosch et al., 1992

It is desirable to develop calibration curves of the flume to avoid the risk of inaccuracies in the dimension of the flume. One of the important characteristics of the Parshall flume is its ability to withstand a relative high degree of submergence over a wide range of backwater conditions downstream from the structure and still maintain free flow conditions.

Rectangular notch

It is placed at the outlet taking off from the main conveyance (i.e. off-takes from the tertiary canal). A rectangular notch is generally used for flow measurement at fixed working head of water. The depth of flow in the notch determines the velocity and multiplied by its width the quantity of water is determined. R-notch works at a working head varying from 15 cm to 30 cm. The measurement is easier by fixing the weir at a suitable sill below the full supply level (FSL) of the channel. The depth of flow is more or less constant and the linear length of the notch releases the required discharge. Thus for different discharge needed for the tertiary canal, rectangular notches of different linear lengths with suitable working head are provided. It is automatically operated at least human interference and is easy to replace and maintain.

3.1.6 Measurement of water flow

Diversion structures

In a diversion structure one gauge is to be established on u/s of the head regulator to determine pond level and the other on the d/s end of the under sluice floor few meters away from d/s so as not to be affected by the d/s flow conditions like jump etc. The zero of the u/s gauge is to be fixed at the sill level of the under sluice. Another gauge is to be fixed at d/s abutment wall of head regulator to guide the height of rising of the vertical gauge for releasing the required discharge.

Main conveyance system

The main conveyance has to carry the total discharge needed for the peak crop water requirement. It must be capable of distributing the required water in all canal outlets simultaneously and thus the sum total of the discharges of all canal outlets is the discharge at the head of the main conveyance. Measurement of flow is to be recorded at the following points.

i. Head of the canal .i.e. downstream of outlet structure;
ii. Off- taking points of tertiary canals;
iii. At the tail end of the tertiary canals-at intervals by indicating the FSL mark in the canal section and upstream of structures; and
iv. At drop structure regulators, siphons and aqueducts.

Structures

The head of water passing a drop structure being known the usual formula is to be adopted to determine velocity of flow (V = $\sqrt{2gh}$). In a siphon the u/s and d/s water gauge enable to work out the driving head and calculate the discharge if the size of pipe is known.

Off-takes

The branch conveyance or a tertiary canal is taken out from the main conveyance. A rectangular notch is best suited for measuring the discharge of the off-taking channel by fixing the sill at suitable depth below the FSL and providing the notch of required length. It works at a head of 15 cm to 30 cm.

Escapes

The depth of water flowing over the structure is to be recorded, H. The width of the escape being known (w) the discharge can be computed by a broad crested weir formula,

$$Q = 1.7H^{3/2} \times w \qquad (7)$$

Drains

Gauge points are to be permanently laid at the end of each primary drain, beginning and end of the main drain. According to water slope of the drain and bed material, a gauge discharge curve is to be established to find discharge at any depth of flow.

3.2 Procedures and methods of operation

The systematic and rational operation of the system goes a great way in achieving the goal for which the scheme exists. The main purpose of the scheme is to yield best results and achieve the targets of food production, improvement in livestock, social happiness, improvement of economical and financial status and preserving the environment for better ecology, health and happiness. The members of the PCC and WUA are associated with the scheme from its inception stage and have to be aware of the functions of components. The water diverted from the river and the system connected from the delivery up to escape have to be regulated, operated in such a manner that the scheme gives full benefit with a maximum coverage without wasting water, creating water-logging or salinity problems.

For the medium scale irrigation projects the management and regulation is controlled by the PCC but for small scale irrigation projects the management & regulation is handed over to the WUA. Such prior arrangement for training and capability building has to be done and regular workshops are to be programmed. It has to be clear whether the irrigation is to be done during daytime or both day and night times. Accordingly the hours of regulation of outlet and infrastructure have to be adjusted. Normally one day in a week is kept as a non-working day may be Sunday or a market day. Then the first day of the week is considered as the day following the holiday. The system involves operation of all hydraulic structures right from the head works up to escape drain.

3.2.1 Diversion weir

In case of a diversion weir the outlet is called head regulator (H/R) and the gauge fixed on the u/s pond will enable to assess the discharge released through the head regulator. In this case reading of d/s gauge fitted on the end of abutment of the H/R is also taken. The record of lifting of vertical gate (i.e. opening) is to be adjusted by putting a gauge along the hoisting arrangements to deliver a required discharge from the pond. The pond level is to be maintained. As it is a diversion scheme the flow in the stream will maintain the pond level with proper operation of under sluice gates as indicated below

i. Operation of under sluice gates should be done during rainy season so that the high velocity created in the under sluice carries the silt away for a long distance and a deep channel is formed in its front.
ii. The leakage through the gates (bottom or sides) needs to be prevented.
iii. Operation of under sluice is to be done monthly or seasonally depending upon the flow so that the pond level is maintained and a deep channel is also created in front of the under sluice.
iv. In lean flow no overflow through the main weir structure is to be encouraged. All discharge is to be regulated through under sluice.
v. Operation of shutters of the head regulator is to be done by raising it to a specified height every day to release required water as per rotational water supply system requirement.
vi. The head regulator should not be operated when heavy silt is incoming in the river during rainy season unless there is sufficient arrangement for a silt ejector in the main conveyance and there is an unavailable actual demand for the command area.

3.2.2 Farm infrastructure

A close contact and correlation is required between the operation of outlets and that of the main conveyance so that release of water from the outlet head regulator is accepted by users running the system without any wastage or escape waters. The demand for water is to be given when it is found that the entire system is fully prepared to people utilizing the same. In case of any damage in any part of the system part supply can be made on special case till the damage is repaired but with due caution so as to avoid damage on other portions or wasteful discharging of the water.

The main and subsidiary canals have to run on "on-off" basis in the rotational water supply system as stated above i.e. either flow full (on) or remain closed (off). Canal has to run on weekly basis always at full capacity so that all outlets can run full with least human interference and equitable volume of water distributed proportionally to all fields within the limited time of one working week of 6 days or more, precisely 12x6 = 72 hours, or 6x18 =108 hours as the case may be. The canal is to be operated for one week continuously and in case the need of crop water is less during subsequent week without harming the growth of the crop the canal will remain closed and be opened only in the next or after two weeks as per the requirement of crop depending upon soil moisture, crop stress, crop sustainability, rainfall and climate.

4 Environmental issues

Before a decision on the implementation of irrigation projects is taken, it is necessary to know their possible environmental effects. This can be effected through environmental impact assessment studies (EIA). When the EIA is integrated in to the project from the pre-feasibility stage, it is possible to see the likely environmental impacts. This may help in preventing many of the negative effects by considering different design alternatives or by suggesting appropriate mitigation measures. If the impacts are detrimental, the project can be stopped at its early stage before unnecessary extra costs have incurred.

However these advantages and facts pertaining to the environment will have little value if they are not properly guided and based on adequate environmental guidelines. Hence the preparation of environmental impact assessment guidelines for the study of irrigation projects will help to assure the proper inclusion of EIA in irrigation development studies and will also guide what to be done at what stage of the project cycle. EIA usually includes the technical aspects of the environmental study including data gathering, prediction of impacts, and comparison of alternatives and the framing of conditions. Irrigation projects can be developed on virgin lands or an existing irrigation system by improving and expanding it.

Irrigation projects help in increasing crop production thereby improving the economic well being and quality of life of the target population. However some can negatively affect the natural and human environment. Serious disruption of the social structure and infrastructure can be the result if an irrigation project functions for generations or more and becomes inoperative because of water-logging, shortage of water, siltation, saline/alkaline conditions, erosion, or removal of nutrients by leaching water. Abstraction of flow from river causes the reduction of flow downstream and the deterioration of water quality. These adverse conditions can destroy the flora and fauna on the affected areas. In some cases, environmental impacts that undermine sustainability occur not as a direct result of the development, but as a consequence of changes elsewhere in the catchment. For example, sedimentation in irrigation channels may be caused by erosion upstream (McCartney et al., 2007).

Irrigation agriculture and crop intensification are accompanied by increased use of chemical fertilizers, insecticides, herbicides and fungicides. These chemicals can alter soil fertility and can pollute surface and ground water resources in its reach. Frequently lack of environmental considerations in the design and construction commonly lead to increased disease incidence in particular vector borne diseases among the local population. The main vector born diseases include Malaria, Schistosomiasis, Lymphatic filariasis and Onchocerciasis (river blindness) particularly malaria is prevalent in the Ethiopian situation.

Irrigation development often requires from local population drastic changes in their habits and habitats. This aspect of humans is sometimes overlooked in irrigation projects when all major decisions concerning the project are discussed and approved at high government levels without consultation with the people for whom these decisions were made in which case local people develop negative attitude towards the scheme. In order to ensure that future developments are sustainable it is essential to integrate environmental concerns into development activities. Environmental impact assessment and management have been recognized as effective tool for facilitating the inclusion of the principles of sustainable development into development processes or projects.

EIA seeks to compare the various alternatives which are available for any project. Each alternative has economic costs and benefits as well as environmental impacts both adverse and beneficial. Adverse impacts may be reduced at higher project costs. Conversely economic benefits may be enhanced at environment cost. EIA is based on predictions and the technical work involved is estimating the changes in environmental quality which may be expected as the result of the proposed action. EIA attempts to weigh the environmental effects on common basis with economic costs and benefits in the over all project evaluation. This helps the decision maker not to overlook environmental consequences in arriving at a decision.

5 Institutional aspects

Farmers who would be benefited from the irrigation scheme need to be organized into associations to make the best use of the available resources in their command. The members of the association can exchange views and ideas and choose the best options to use the available irrigation scheme efficiently. Such associations need to be legally institutionalized to carry out the functions of water distribution, maintenance, and repair and over all management. WUA could be organized and legalized on the basis of agricultural cooperatives proclamation. Organizing and institutionalizing the farmers in WUA gives more attention and more power than organizing them in other forms.

5.1 Community and beneficiaries participation

Community participation may be defined as the process by which people are able to organize themselves and through their own organization, are able to identify their own needs, share in the design, implementation and evaluation of the development project (ESRDF, 1997). Participation helps the community/ beneficiaries to involve themselves in identification, design and implementation of development programs. It helps to give their voice in development decision making, access to productive assets and share in development programs.

The application of participatory methods sensitizes the beneficiaries, increases their receptivity, ability to respond to the program immediately and encourages local initiatives. Based on the above conceptual frame work of participation, the procedures of involving beneficiaries and community at different stages of the irrigation scheme need to be designed. The target beneficiaries of an irrigation scheme are those farmers who could benefit from the scheme by using irrigation for their farm plots.

5.2 Procedures for ensuring participation of the community and the beneficiaries

District Agriculture and Rural Development and Cooperatives Office subject matter specialists together with the concerned district level government authorities; NGOs and development agents involved in the promotion of irrigation schemes have to make sure that the direct beneficiaries and the community within the area of the scheme are aware of the project and fully participate in the identification, preparation, construction, implementation, management, monitoring and evaluation. The awareness and participation of the beneficiaries and/ the community could be implemented using Participatory Rural Appraisal technique. PRA technique helps to facilitate development and promotion of irrigation schemes as opposed to a project that is initiated from the top. The approach improves the relationship between the beneficiaries and the concerned government authorities.

At the initial stage of an irrigation scheme the beneficiaries and the community could be grouped into smaller groups to facilitate full participation and discussion on the different issues of irrigation schemes that could be raised. General consensus and agreement made need to be recorded for further analysis and clarification. If total agreement is made about the diversion irrigation scheme it is possible to establish the community project committee (CPC) which facilitates genuine participation of the beneficiaries and the community. A detailed description of the envisaged irrigation scheme with pertinent technical documents have to be made available to the CPC; an organization which later on will be converted into WUA at operation level along with a copy of technical handbooks for their study, guidance and follow ups.

5.3 River diversion study and design

Beneficiaries of the river diversion irrigation scheme through which the canal passes and the downstream users need to participate in the study and design of the project right from the very beginning. The farm land area to be covered and the number of beneficiary farmers of the irrigation scheme needs to be determined through participatory method during the initial design and study of the project. Beneficiaries need to participate in the socio-economic survey of area coverage, distance from diversion point to farm land area, natural resources and farm land size that is to be affected by irrigation system and the like.

Participatory methods of decision making could be based on organizational groups of beneficiaries, individual farmers who might not benefit from the river diversion but affected by the canal and the downstream users. The beneficiary group of the irrigation scheme could be organized in to WUA which has a permanent nature while the other groups who might not benefit could be organized on temporary basis to protect their rights. Methods of participation could be through group discussion, workshops and seminars.

5.4 Construction of canal and infrastructures

The primary sources of labor for such construction work have to come from the scheme beneficiaries of small scale irrigation. Such labor contribution from the beneficiaries could be on free basis. But for the additional labor force required from the community, payment in cash or through food for work depending on the locality or the region could be made. Such arrangements could be determined in advance before the commencement of construction. The identified beneficiary groups of small scale irrigation scheme from river diversion are encouraged to establish CPC which helps to take the lead in the construction of weir and off-take canal. It is at this early stage that the association is expected to start playing a role in the management of construction of the diversion weir and the canal. Under all circumstances of labor contribution by the direct beneficiaries, it is considered in the cost recovery calculation.

5.5 Handing over of the scheme

The completion of an irrigation scheme should be marked by physical handing over to WUA organized and legalized for operation and maintenance. Certificate of handing over of the scheme signed by the construction agency and the leader of the WUA has to be done for the same. The original signed certificate has to be handed to WUA while the copy remains with the construction agency. There after it is the responsibility of the WUA to manage, operate and maintain the irrigation scheme through its executive committee. It is worthwhile mentioning here that at the initial stage of introduction of the irrigation scheme; it is quite possible that WUA could not be able to repair and maintain the system to the desired level of performance as learnt through experience. Hence there should be a provision of some amount of fund at least during the gestation period (2-3 years) to assist WUA in covering operation and maintenance cost.

Post handing over of the irrigation scheme, monitoring and evaluation is important to see the implementation and evaluation impacts. Experiences gained from monitoring the irrigation scheme help to improve the design and appraisal of other new schemes to be developed in the future. In view of the importance of monitoring and evaluation of irrigation schemes, frequent visit is required by the Water Resources Development Bureau operation and maintenance department to give the support in case of major maintenance. The monitoring and evaluation of the scheme includes utilization of irrigation water, the number of beneficiaries, fulfillment of obligations like management, maintenance, repair, collection of users fees, performance of any cooperating agencies such as Government Bureau, NGOs and other required inputs. Evaluation need to be carried out to assess the impact of irrigation schemes on the beneficiaries and to determine whether the original objectives have been meet or not.

II The case study

6 Introduction

Agriculture is the basis of economy for people in the project area. Farmers in the project area practice mixed farming system where they raise crops and rear animals. Especially crop production is the predominant economic activity in the area even though it is mainly rain fed and for subsistence purpose. In spite of its importance, generally agriculture in the area is operating at low technology and poor yield. Consequently the peasant community in the area is suffering from poor standard of living and low income.

Therefore, to alleviate this problem irrigated farming was proposed for full and supplementary irrigation by which sustainable and increased crop yields can be obtained. Along with the introduction of irrigation, other associated agricultural packages such as high yielding varieties, use of fertilizer, application of improved crop management practices, provision of strong extension service and credit facilities were planned. Hence through the use of this project 65 ha of land was planned to be cultivated both in dry and wet season crop production. But currently the size of the irrigable area has increased to 83 ha and the number of beneficiary households is 271 according to the extension agent.

Nevertheless, such development projects need to be established on sufficient study of the various aspects of the site including hydrologic, geologic and physical conditions, farming system and socio- economic situation. This study tries to identify major areas of planning ,design and operation that were given prime importance in establishing Kulanti irrigation project that are stipulated to ensure the sustainability of increased food production for the locality in particular and the region in general. The result of the findings could be used as a reference guide for the planning of new projects in the region and comparison will be made against the comprehensive planning aspects explored in the literature review section.

7 Description of Kulanti irrigation project

7.1 General

When studying the agronomy and soils of the project area, it is necessary to describe the project area in terms of rainfall, climate, topography, soils and its geographic coordinates to give a quick impression to the reader. Kulanti IP is found in Amhara regional state, Awi Administrative Zone, Ankesha District and within Jabella lideta peasant association. The area is located 6 kms away from the district center, Gimja Bet, in the south direction and 25 kms away from zonal town, Injibara. The geographical coordinates of the project area lay between 10°47'39" N altitude and 36°51'64" E longitude. And the latitudinal range of the command area varies from 2190 masl as maximum and 2120 masl as minimum with a river bed elevation of 2171.0 masl (ORDA, 1999).

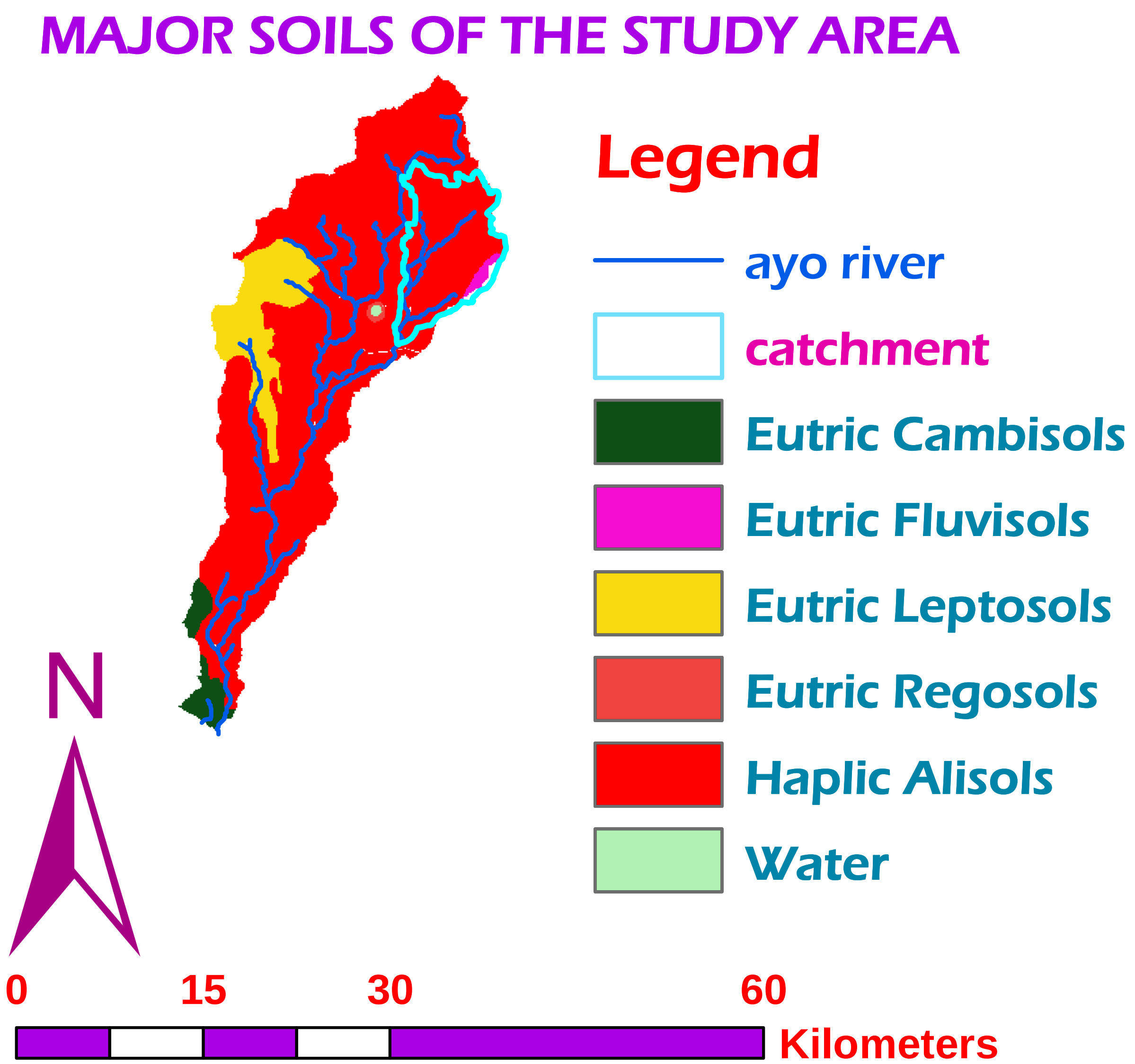


Figure 13 Major soils of the study area

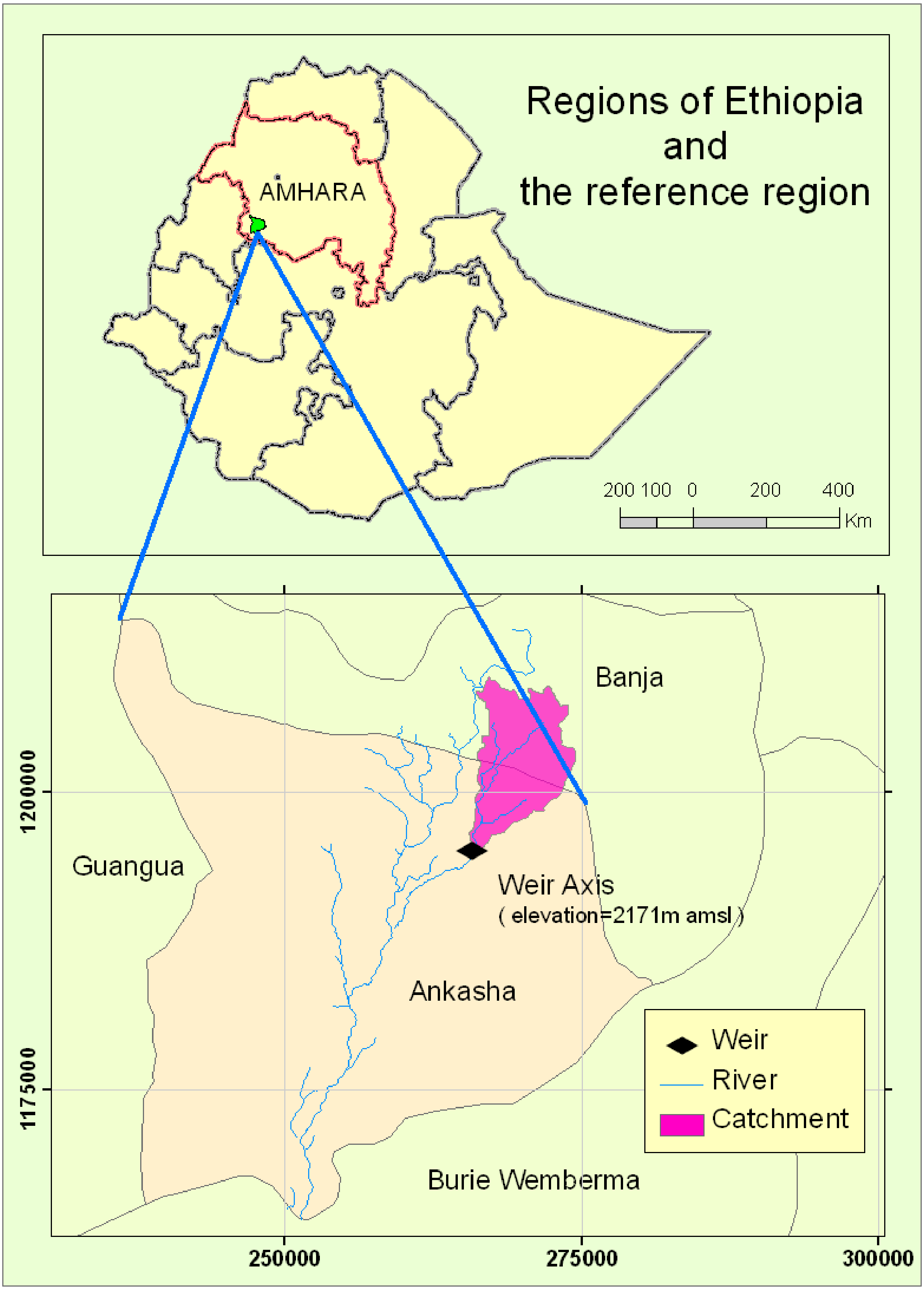


Figure 14 Location map of the research area, Amhara Region BoWRD,2008

7.2 Climate

The project area is categorized under 'Woina Dega' agro climatic zone. The mean maximum annual temperature of the area is 24.9 °c with a maximum value of 28.3 °c occurring in March and April and the mean minimum annual temperature is 8.9 °c with a minimum value of 4.4 °c occurring in January. The project area receives about 1540 mm average annual rainfall. The rainfall pattern is mono-modal type which prevails mainly from late may to early October. Specially, the highest rainfall occurs from late June to early September where about 80 percent of the annual rainfall falls. Though the total annual rainfall seems high, its late start at its onset and early stop of the rainy season created problem on crop production.

With respect to relative humidity the area has got a mean annual relative humidity of 65.3% with monthly minimum average relative humidity of 47.4% and maximum 85% which occurs in the months of March and August respectively. Wind speeds measured at a height of 2 m from the ground surface indicated that the highest wind speed occurs in the month of April and May and the lowest in October and November, as shown in the annex. Sunshine hour as one of the climatic factors influencing rate of evapotranspiration in an area is measured and is found to vary from month to month. The mean longest and shortest sunshine hours occurred in the months of January and August respectively with corresponding values of 9.2 & 4.2 hours.

The climatic elements stated above are the major factors influencing crop water requirement thus have to be monitored on regular basis for efficient irrigation water management. The summary of the climatic data of the project area as adopted from Dangila Meteorological Station is presented in appendix 7.1. The values of weather data from NMSA and the one managed by FAO are slightly different but the values of the latter are adopted for the estimation of crop water requirement that is associated with CROPWAT software under the name of *ETHCLIM* data electronically.

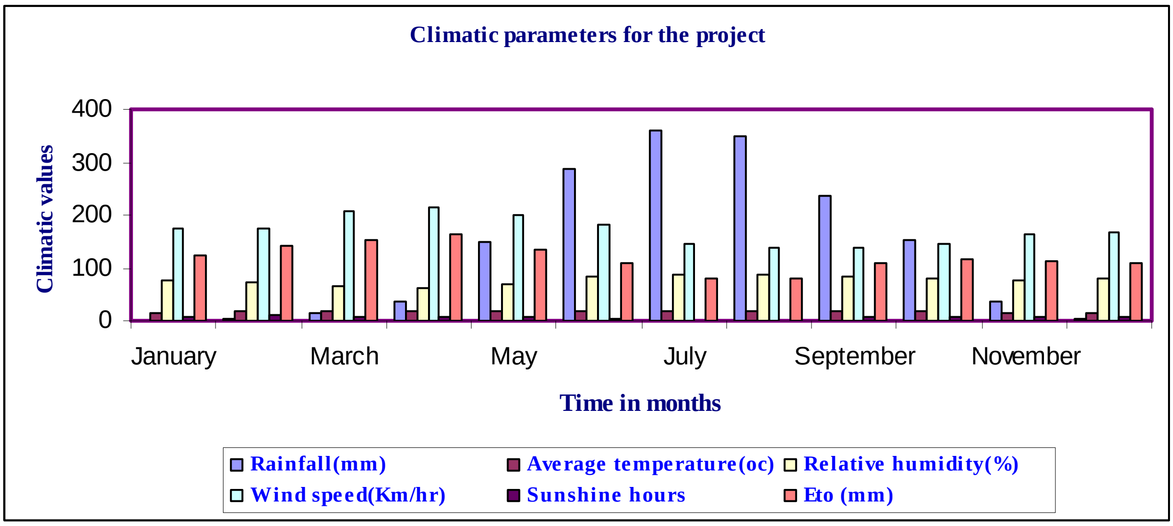


Figure 15 Average climatic parameters of Kulanti IP

Table 3 Estimation of reference crop evapotranspiration using CropWat program

```
5/12/2008                                                  CropWat 4 Windows Ver 4.3
******************************************************************************
                          Climate and ETo (grass) Data
******************************************************************************
Data Source: C:\ETHCLIM\DANGILA.PEN
------------------------------------------------------------------------------
Country: Ethiopia                    Station: DANGILA
Altitude: 2180 meter(s) above M.S.L.
Latitude: 11.17 Deg. (North)          Longitude: 36.55 Deg. (East)
------------------------------------------------------------------------------
Month        MaxTemp MiniTemp Humidity Wind Spd. SunShine  Solar Rad.    ETo
             (deg.C) (deg.C)    (%)      (Km/d)   (Hours)   (MJ/m2/d)   (mm/d)
------------------------------------------------------------------------------
January        27.0    4.2      78.0     173.0     8.9         20.1        4.15
February       27.9    5.2      71.0     173.0     9.4         22.2        4.71
March          28.6    6.1      67.0     207.0     8.1         21.6        5.15
April          28.1    8.0      61.0     216.0     8.8         23.1       [5.44]
May            27.1    9.0      70.0     199.0     6.3         18.9        4.52
June           25.0    9.5      82.0     181.0     4.8         16.4        3.59
July           23.0    9.9      89.0     147.0     1.8         12.0        2.62
August         23.1    10.2     88.0     138.0     1.6         11.9        2.61
September      23.9    10.1     85.0     138.0     6.5         19.2        3.61
October        24.9    8.8      80.0     147.0     7.6         19.9        3.82
November       24.8    7.4      78.0     164.0     8.1         19.2        3.71
December       26.2    5.2      80.0     147.0     8.1         18.4        3.64
------------------------------------------------------------------------------
Average        25.8    7.8      77.4     169.2     6.7         18.6       [3.96]
------------------------------------------------------------------------------
Pen-Mon equation was used in ETo calculations with the following values for
Angstrom's Coefficients:
            a = 0.25         b = 0.5
******************************************************************************
C:\CROPWATW\REPORTS\ETOOLD.TXT
```

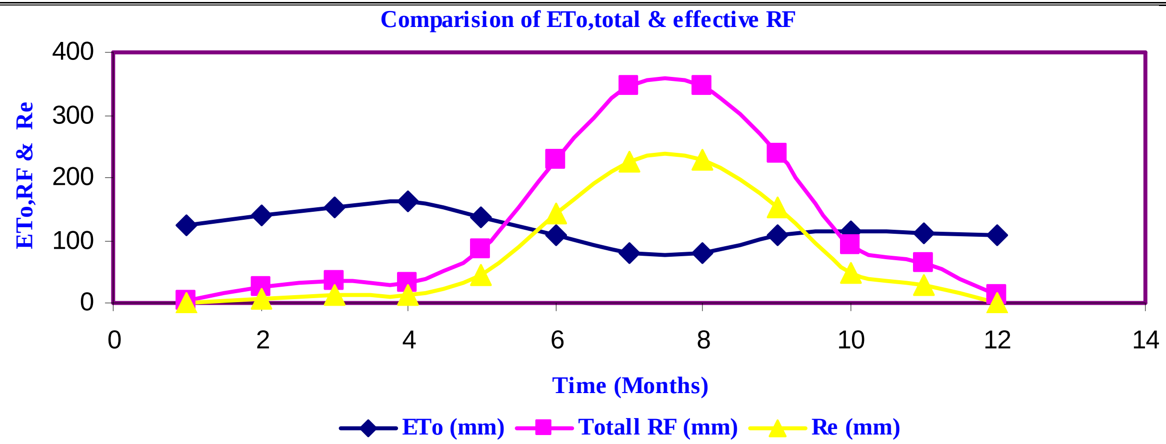


Figure 16 Comparison of ETo, total and effective RF values for the project (mm)

7.3 Topography and soil

Generally, the topography of the project area varies from flat to moderate where as with respect to cultivable command area; the mean transversal slope is 1.67% with maximum elevation of 2190 masl and a minimum value of 2120 masl. The soil of the project area has been studied using field observation and laboratory analysis. For this soil profile test pits have been dug at two locations and sampled for laboratory analysis. Based on the study, it is found that effective soil depth is not a problem. Regarding sample preparation for analysis, the soil samples were air-dried at room temperature by spreading on plastic trays. Then they were ground by a grinding machine and sieved through a 2 mm sieve.

The particle size distribution was determined by modified Bouyoucos method. 50 gm soil was soaked with 100 ml distilled water for 24 hours. Then 40 ml of 5% sodium hexameta phosphate (calgon) was added and the suspension was then transferred to hydrometer Jars stirred for 5 minutes and the volume was made to one liter by adding distilled water. The hydrometer readings were taken at 40 seconds and 2 hours intervals to calculate the silt plus clay and clay percentage respectively. Sand percentage was calculated by subtracting silt plus clay percentage from 100%. The predominant soil texture is clay (from an average composition of sand, silt and clay 16%, 26.3% and 57.7% respectively)

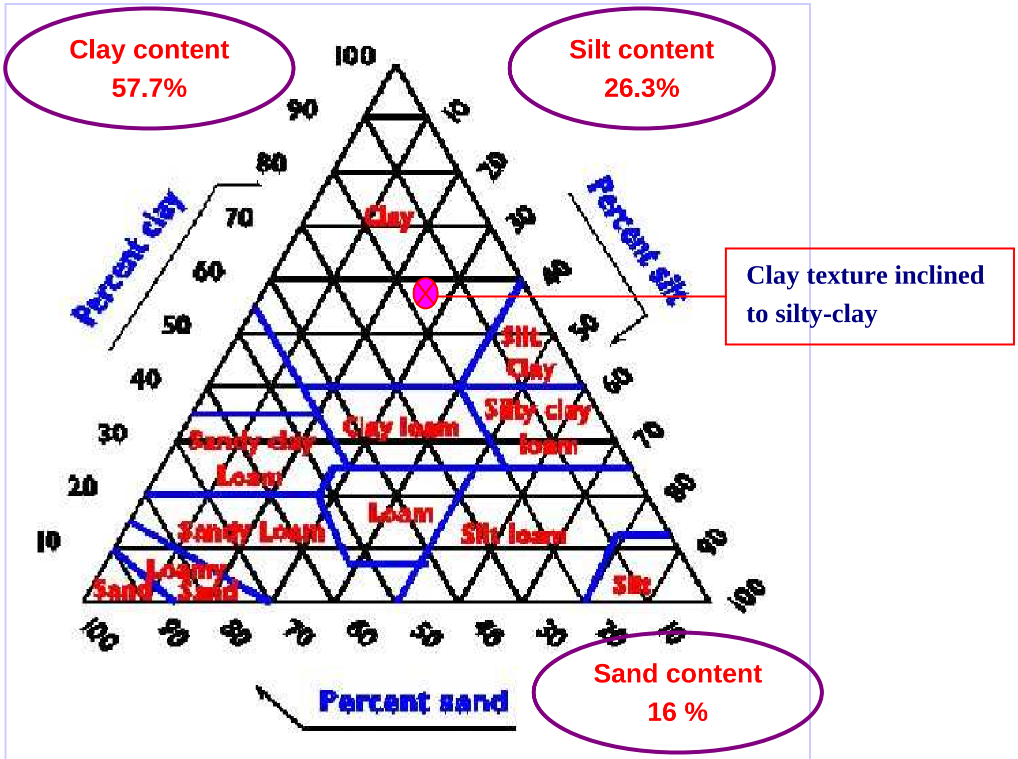


Figure 17 Textural soil names based on percentage composition; Prinz 2007

And the pH of the soil ranges from 5.3 to 6.3. This is the preferred range for most crops lower end of range too acidic for some. The feasibility study conducted in 1999 showed that the pH of the soil ranged from 4.91 to 5.35. Possible reasons for the increase may be use of more alkaline fertilizer for the irrigated farm or leaching out of salt traces from higher precipitation. Generally the soil of the study area is potentially suitable for irrigation. However, it requires some sort of drainage network since the predominant soil texture is clay and the land form is having some what gentle slope. A detail of the soil analysis is given in annex 7.2.

Soil moisture content

A soil being an aggregate of soil particles having a porous structure the pores may have water or air. If voids are fully filled with water the soil is saturated and if voids have only air the soil is said to be dry (Prakash, 1996). Soil physical test was undertaken on undisturbed soil samples in the laboratory which is basic data on soil water movement through the profile and water retention in the soil to primarily assist the planners in designing the irrigation water supply. The soil profile was divided into layers and each layer is divided into 30 cm deep. It was preferred to start collecting the undisturbed sample at the bottom layer.

The sides of the soil profile at each layer were drilled laterally to enable the placement of the core cutter with sufficient space provision for hammering the core cutter. Two core cutters were driven into the soil body to take undisturbed soil sample at each layer. The soil cores were taken to the Bureau of Water Resources Development soil laboratory for measurement of bulk density and moisture content. Required inputs to undertake the sample collection were cylindrical steel core cutters of 5 cm diameter and 5 cm long, labor and digging tools and for the analysis, an oven dry and weighing machines were used in the laboratory. The results are shown in the annex 7.2,Table 26

Electrical conductivity

The electrical conductivity (EC) of a solution is an indicator of the total soluble salts in the sample. The EC was measured on 1:2.5 soil: water suspension. EC values over 4 mS/cm are considered restrictive for most crops and values as low as 2 mS/ cm may affect the more sensitive crops according to Amhara Region Water Resources Bureau (1997). The laboratory analysis result indicated that EC values within the project area are far below the above thresholds and don't impose any limitations on plant growth. The highest value recorded is 1.6 μS/cm and was measured at a depth of 47 cm from the surface and the minimum value of 1.3 μS/cm was measured at a depth of 13 cm from the soil surface. This implies that the high rainfall condition in the area has resulted in the leaching of salt traces in the irrigated farm and salinity is not an issue and there is no need to cater for the leaching requirement during the water supply planning.

8 Water quality analysis

Water quality is judged in relation to its use (e.g. irrigation, drinking, etc) and its suitability to the aquatic life. Quality is defined by several parameters such as its pH, BOD, DO, suspended solids etc and for each criterion there can be a variety of determinants which are more or less suitable and easier or more difficult to measure (Fieredingstad,1963). Important agricultural water quality parameters include a number of specific properties of water that are relevant in relation to the yield and quality of crops, maintenance of soil productivity and protection of the environment. These parameters mainly consist of certain physical and chemical characteristics of water. The physical parameters include total dissolved solids, temperature and electrical conductivity where as the chemical aspects include among others the pH value.

Dissolved salts increase the osmotic potential of soil water and an increase in osmotic pressure of the soil solution increases the amount of energy which plants must expend to take up water from the soil. As a result, respiration is increased and the growth and yield of most plants decline progressively as osmotic pressure increases (Pescod, 1992). Hence the amount of TDS in irrigation water should be below an optimum concentration and here is the result of the analysis for Kulanti River where the irrigation projected is established.

Table 4 Test results of water quality analysis for Kulanti River

Sample no	Date of analysis	Date of sampling	PH	TDS	EC	DO
1	April,2008	April,2008	9.2	27 mg/l	57 μS/cm	0.42 ppm
2	April,2008	April,2008	9.2	26 mg/l	54.3 μS/cm	3.21 ppm

Water with an EC greater than 1.0 mmhos/cm or 1.0 mS/cm would be considered to have a high salinity hazard (Njue and Krug, 2008) where as the EC of Kulanti river which is the source of water for irrigation is on the average 0.11 mmhos/cm which shows non-saline conditions. pH is an important chemical property related to plant growth because of its effect on nutrient availability. Water for irrigation should have a pH between 5.0 and 7.0. Trace elements deficiencies and imbalances of calcium (Ca) and magnesium (Mg) can result from irrigating with high alkalinity water and this fact is reflected in this case (pH 9.2) and hence use of acidic fertilizer is required to lower the alkalinity.

9 Hydrologic and hydraulic design of Kulanti diversion irrigation project

Knowledge on hydrology is essential for those dealing with hydraulic structures such as irrigation and drainage schemes. The availability of water is highly uneven in space and time. Some of the basic things that need to be considered while planning and design of hydraulic structures such as diversion weirs are (Patra, 2003).

i. Maximum flows which are expected to occur at a place.
ii. Minimum flows which can occur during any dry period.
iii. Possible regulation of floods at downstream reaches once a hydraulic structure is erected.
iv. Possible supply of water from a river to meet water supply demands for agriculture, domestic supplies, hydropower power generation.
v. Environmental impact of hydraulic structures.

Improper assessment of water resources potential is disastrous. Many a times under estimation of the flood leads to overtopping of the dam and consequent failure of the structure. For those projects where the water potential was over estimated the system may not be in a position to meet the demand, for instance peak crop water requirements. Before designing any water resources related structure evaluation of the hydrologic potential at the project site is a prerequisite. For this collection and analysis of long term hydrological and meteorological data like rainfall, runoff, and infiltration characteristics etc for the area is essential. In a developing country like Ethiopia long term data is hardly available and the most commonly available one is precipitation data.

In this case Kulanti River is not gauged like most rivers of the country and one means to generate the peak runoff is to relate the catchment characteristics and its land use. For this purpose a design rainfall of 50 years return period is selected for this minor hydraulic structure i.e. for Kulanti diversion weir. Thus the design flood magnitude is computed from storm rainfall of 50 years return period using Soil Conservation Service Curve Number (SCS-CN) method. The major input data used in the determination of the peak discharge as indicated below is the daily maximum rainfall of Dangila Rain gage Station over 15 years. The Chow's frequency factor method is used for estimation of the design point rainfall depth for the catchment; which implies the assumption that this point rainfall is distributed over the whole catchment.

Table 5 Statistical analysis of maximum one day rainfall for flood computation using Chow's method

Rank	Natural series order	Rank	Natural series order
1	41	10	65
2	34	11	48.5
3	51	12	58.2
4	36	13	34
5	50.5	14	53.5
6	57	15	26
7	55	$\overline{X}$	47.38
8	43	σ	11.20
9	58		

From Chow's method of frequency factor, rainfall of return period of 50 years;

$$X_{50} = \overline{X} + K\sigma \tag{8}$$

Where K is frequency factor and is a function of sample size, "n" and return Period, "T". In this case "T" is 50 years and "n" is 15 and from tables of frequency factor for Gumbel distribution, "K" is 3.321 from appendix 7.1, Table 28.

$\overline{X}$ is the mean of the daily maximum rainfall values and σ is the standard deviation.

$$\boldsymbol{X_{50} = 47.38+3.321(11.20) = 84.58\ mm}$$

9.1 Peak runoff determination

For drainage basins where no runoff has been measured the Curve Number Method can be used to estimate the depth of direct runoff from the rainfall depth given an index describing runoff response characteristics. The Curve Number Method was originally developed by the Soil Conservation Service (Soil Conservation Service 1964; 1972) for conditions prevailing in the United States. Since then it has been adapted to conditions in other parts of the world. The Curve Number is a dimensionless parameter indicating the runoff response characteristic of a drainage basin. In the Curve Number Method this parameter is related to land use, land treatment, hydrological condition, hydrological soil group, and antecedent soil moisture condition in the drainage basin.

Table 6 Curve number determination according to SCS-CN method for Kulanti catchment

S/n	Land use	Ratio	Hydrologic condition	Treatment practice	Curve no	Weighted CN	Hydrologic Soil group
1	Crop land	0.5	Poor	Straight row	84	42	C
2	Farmsteads	0.4	poor		74	29.6	B
3	Pasture	0.07	Fair		69	4.83	B
4	Meadows	0.03	Good		58	1.74	B

Sum weighted CN for AMC II is 78 and the corresponding CN for AMC III is 90 from appendix 9.1. Basically the hydraulic soil group is determined based on the infiltration rate of the soil prevailing for that particular land use in combination with the land slope and many other interrelated factors. The hydrologic conditions of an area can be expressed as the runoff producing potentials of that area. The infiltration rate is the rate at which water enters the soil at the surface which depends up on the surface hydrological conditions. Thus surface hydrological conditions are divided into three main categories: Poor, fair and good. Poor hydrological conditions have greater value of "CN" and low potential for runoff contrasting to good hydrologic conditions which have low values of "CN" and high potential for runoff (MoA, 1995).

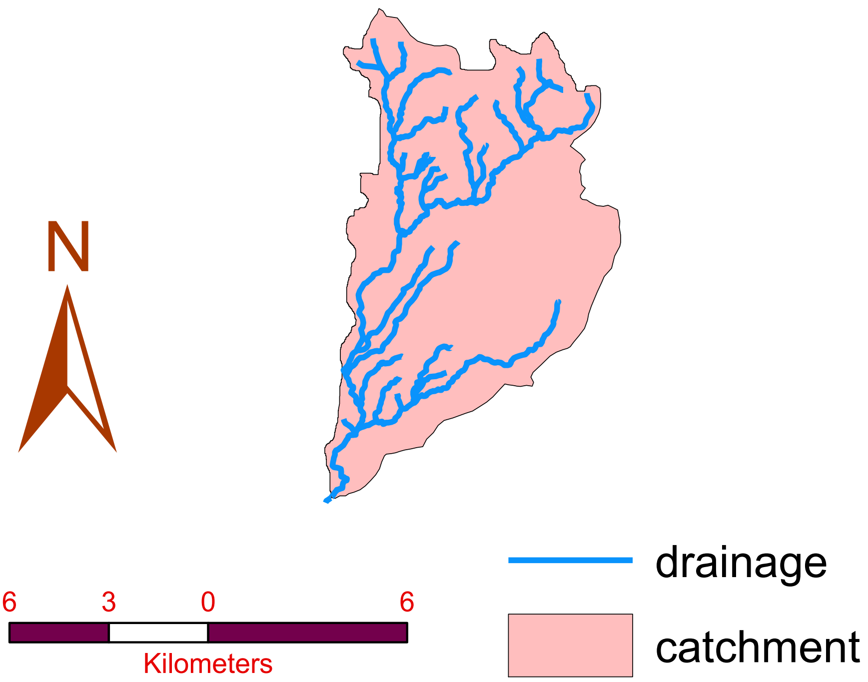


Figure 18 Kulanti Catchment with its drainage features digitized from a topographic map of 1: 50,000

Time of concentration for Kulanti Catchment

The maximum travel time in the catchment is called concentration time, T_C. Based on measurements in very small catchments (Kirpich, 1940) has developed the following formula.

$$T_C = \frac{1}{3000}(L/\sqrt{S_0})^{0.77} \qquad (9)$$

Where Tc is time of concentration (Hour)

L is length of the main stream in m = 19,300 m, the longest stream from the watershed divide to the weir site, that is our point of interest as measured from the topographic map.

S_0 is the river bed slope = 0.017 m/m from the topographic map.

$$Tc = \frac{1}{3000}(\frac{19300}{\sqrt{0.017}})^{0.77} \cong 3.0 \text{ Hours}$$

To compute the direct runoff depth from the catchment; the following formula developed by USDA Soil Conservation Service is adopted.

$$Q = \frac{(p-0.2S)^2}{p+0.8S} \qquad (10)$$

$$S = \frac{25400}{CN} - 254 \qquad (11)$$

$$S = \frac{25400}{90} - 254 = 28.22\ mm$$

Where Q is direct runoff in mm

P is total rain fall in mm

S is rainfall abstraction capacity of the catchment in (mm)

CN is runoff curve number

Substituting "S" by 28.22 mm; the equation is reduced to

$$Q = \frac{(p-5.644)^2}{p+22.576} \qquad (12)$$

9.1.1 Parametric unit hydrograph preparation

The method selected to develop the composite hydrograph of the catchment is the triangular unit hydrograph method in which case the time to peak and time base of the unit hydrograph are developed from the time of concentration of the catchment. Duration of excess rainfall; D, Time to peak; Tp and time to base; Tb are estimated as follows (Soil Conservation Service 1964; 1972)

$$D = T_C / 6 \tag{13}$$

$$T_p = 0.5D + 0.6T_C \tag{14}$$

$$T_b = 2.67T_p \tag{15}$$

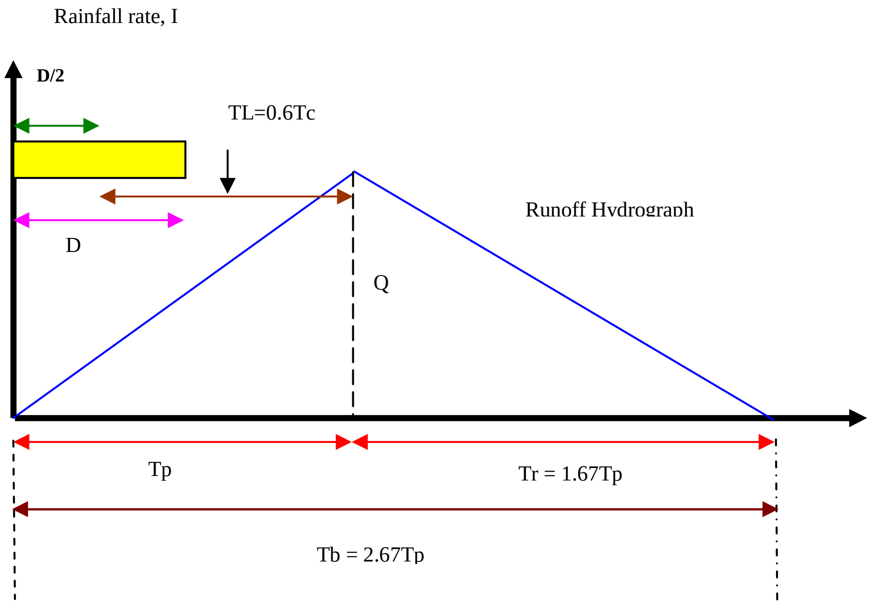


Figure 19 Triangular hydrograph for runoff estimation for Kulanti catchment

The area "A" under the triangle which is the volume of direct runoff, is given by

$$A = 1/2 \times q_p \times T_b \tag{16}$$

Volume of runoff = Area of catchment × depth of runoff
Depth of runoff = 1mm
Therefore volume of runoff is $1/2 \times q_p \times T_b \times 1mm$

Where; q_p= Peak runoff of the UH in m^3/s

$$q_p = \frac{2 \times A}{T_b} \times 1mm$$

$$= \frac{2AQ}{2.67T_p}$$

$$q_p = \frac{0.208AQ}{T_P} \tag{17}$$

(For 1mm runoff depth)

Where; q_p is peak runoff in m^3/s
A is catchment area in km^2 and it is 71.25
Q is runoff volume in mm
Tp is time of peak in hours

q_p for this catchment is computed as ; $q_p = \frac{(0.208)(71.25)}{2} = 7.3m^3/s$,For 1mm runoff depth. The unit hydrograph preparation technique and the peak flood magnitude determination are shown in the subsequent tables; Table 7,Table 8 and Table 9 with the help of annex 9.1; and Table 29.

Table 7 Determination of rainfall depth for Kulanti catchment for the given rainfall duration

Duration (Hr)	Daily point rainfall of a 50 yr return period (mm)	Rainfall profile (%)[1]	Rainfall profile (mm)	Area to point rainfall ratio (%)[2]	Area rainfall (mm)	Incremental rainfall (mm)
0 – 0.5	**84.58**	35	29.603	57.60	17.051	17.051
0.5 – 1.0		40.5	34.255	67.60	23.156	6.105
1.0 – 1.5		50.5	42.713	71.525	30.550	7.394
1.5 – 2.0		58	49.056	75.450	37.013	6.463
2.0 - 2.5		63	53.290	77.450	41.273	4.26
2.5 – 3.0		67	56.670	79.45	45.024	3.75

Table 7 continued…

Descending order	Rearranged incremental rainfall(mm)	Cumulative rainfall(mm)	Time of incremental hydrograph		
			Time to begin	Time to peak	Time to base
17.05	3.75	3.75	0	2.05	5.47
6.844	6.105	9.855	0.5	2.55	5.94
6.463	6.463	16.318	1.0	3.05	6.47
6.105	17.051	33.369	1.5	3.55	6.97
4.26	6.844	40.213	2.0	4.05	7.47
3.75	4.260	44.473	2.5	4.55	7.97

From this rearranged values of rainfall depth; it is possible to calculate the cumulative direct runoff from equation (10).

P (mm)	***Q (mm)***
3.75	0.136
9.855	0.548
16.318	2.932
33.369	13.744
40.213	19.037
44.473	22.491

[1] Interpolation values from graph developed by USSCS attached as an appendix

[2] Interpolation values from tables which is a function of catchment area and duration of rainfall developed by USSCS and attached as an appendix

Table 8 Triangular hydrograph for Kulanti catchment calculated according SCS-CN method for the given rainfall depth and catchment size

Duration	Cumulative runoff	Incremental runoff	Peak runoff for increment[3]	Time of beginning	Time to peak	Time to end
(hr)	(mm)	(mm)	(m^3/s)	(hr)	(hr)	(hr)
0 – 0.5	0.136	0.136	1.0	0.0	2.05	5.47
0.5 – 1.0	0.548	0.411	3.0	0.5	2.55	5.97
1.0 – 1.5	2.932	2.384	17.403	1.0	3.05	6.47
1.5 – 2.0	13.744	10.812	78.928	1.5	3.55	6.97
2.0 – 2.5	19.037	5.293	38.639	2.0	4.05	7.47
2.5 – 3.0	22.491	3.454	25.214	2.5	4.55	7.97

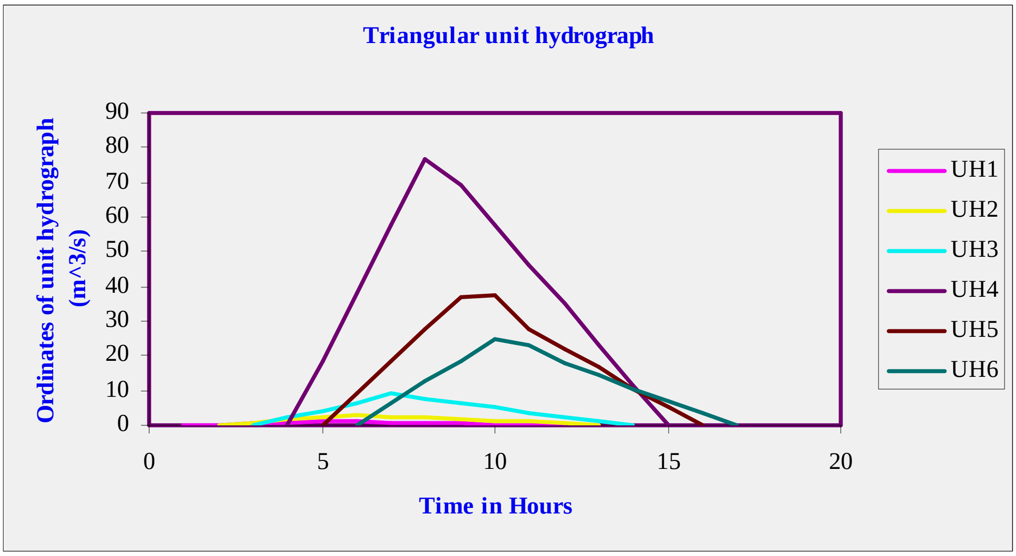


Figure 20 Triangular hydrograph for Kulanti catchment

[3] Peak discharge created by 1mm of runoff is 7.3 m^3/s and the discharge from the respective runoffs is calculated accordingly ,e.g. for 0.136 mm runoff ,it is 0.136 mm*7.3 $m^3/s/m \cong 1.0$ m^3/s as indicated in table 6

Table 9 **Synthesis of composite hydrograph, calculated according SCS-CN method**

Time in hour	Ordinates of a hydrograph (m^3/s)						
	UH1	UH2	UH3	UH4	UH5	UH6	Total
0.0	0						0.0
0.5	0.2	0					0.2
1.0	0.5	0.75	0				1.25
1.5	0.75	1.5	2.25	0			2.5
2.0	1.0	2.25	4.25	18.5	0		26
2.5	1.0	3	6.5	38	9	0	57
3.0	0.75	2.5	9	57.5	18.5	6.5	124.75
3.5	0.5	2.25	7.5	77	27.5	12.5	127.25
4.0	0.5	1.75	6.25	69	37	18.5	133
4.5	0.25	1.25	5	57.5	37.5	25	126.5
5.0	0.125	1.0	3.75	46	27.5	23	101.38
5.5	0	0.5	2.5	35	22	18	78
6.0		0	1.0	23	16.5	14.5	55
6.5			0	11.5	10.5	10.5	32.5
7.0				0	5.0	7.0	12
7.5					0	3.5	3.5
7.97						0	0

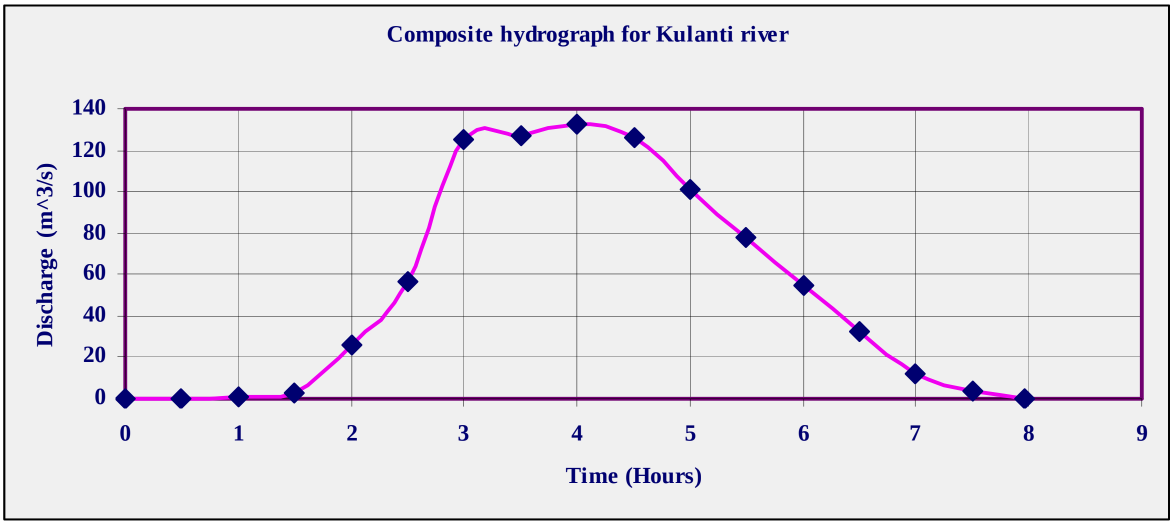


Figure 21 Composite hydrograph for Kulanti catchment

From the hydrograph above; the peak design discharge is found to be **133 m^3/s.** This is the main external loading for the design of the whole system concerning the diversion weir and its components.

9.1.2 Development of stage discharge relationship at weir axis

To evaluate /or fix the maximum flood level, cross-sectional profiles at three sections along the course of the stream where the diversion weir is planned was surveyed; which is commonly named as the slope-area method for peak discharge estimation in remote areas based on Manning's equation for determining the mean velocity in the cross-section (Buck, 2006). Using the river bed slope measured by surveying (which **is 0.018**) and velocity-area technique, the discharge at various levels is determined for the three sections i.e. at u/s, at weir axis & at d/s sections. From the rating curves of these sections, the water surface levels of the design flood is obtained and the average water surface slope is determined and the final stage discharge curve (rating curve) is developed for the weir axis using this slope and Manning's uniform flow equation.

Making use of the water surface slope and adopting Manning's equation; it is possible to produce the stage discharge curve where we can fix the high flood level corresponding to a 50 year return period. Since the stream bed slope is not the same as the water surface slope; it is necessary to recalculate the water surface slope from the calculated MFL values at three sections of the river. The following tables depict the hydraulic parameters of the river cross sections at the selected points /or preferably sections.

Table 10 Hydraulic parameters at the weir axis (Kulanti River)

Manning's roughness, n = 0.03				**River bed slope, So=0.018**			
S/N	Elevation	Stage	Wetted area	Wetted perimeter	Hydraulic radius	Velocity[4]	River discharge
	masl	m	m^2	m	m	m/s	m^3/s
1	2171.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2171.5	0.5	4.7	14.0	0.3	2.2	10.1
3	2171.9	0.9	7.5	15.6	0.5	2.7	20.5
4	2173.0	2.0	23.1	18.6	1.2	5.2	119.5
5	2173.7	2.7	37.2	22.2	1.7	6.3	235.1

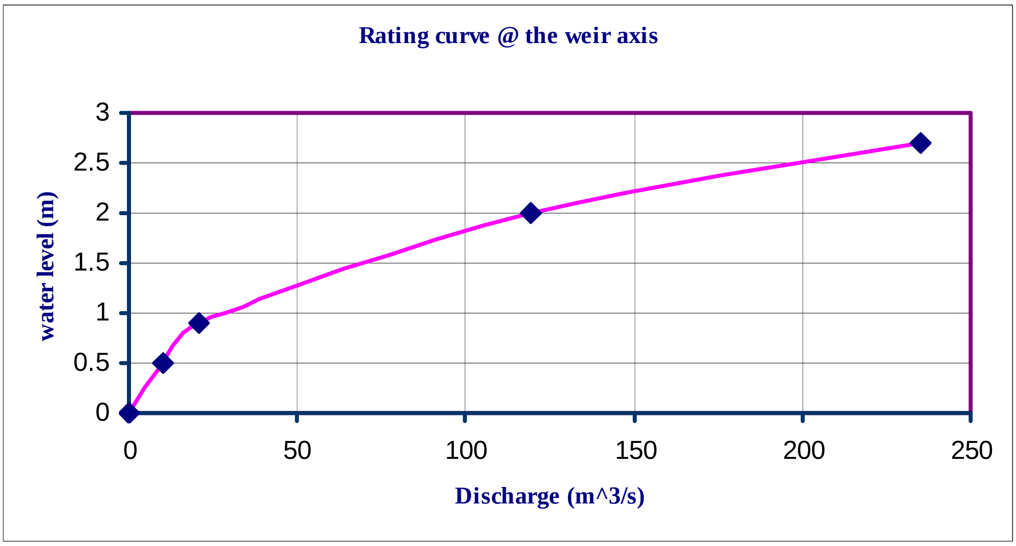


Figure 22 Rating curve at the weir axis for Kulanti River

[4] Velocity, V = $\frac{R^{2/3} * S^{1/2}}{n}$ is known from Manning's equation with "n" equal to 0.03 for the river bed material from the geological investigation report for Kulanti river (ORDA, 1999) and Q = AV

Table 11 Hydraulic parameters at upstream of the weir axis (Kulanti River)

S/N	Elevation	Stage	Wetted area	Wetted perimeter	Hydraulic radius	Velocity	River discharge
	masl	m	m^2	m	m	m/s	m^3/s
1	2172.3	0.0	0.0	0.0	0.0	0.0	0.0
2	2173.0	0.7	6.6	15.0	0.4	2.6	17.1
3	2173.7	1.4	12.0	19.2	0.6	3.3	39.2
4	2174.3	2.0	16.5	22.2	0.7	3.7	60.4
5	2175.3	3.0	22.1	25.0	0.9	4.1	90.9
6	2176.1	3.8	36.6	28.6	1.3	5.3	193.0

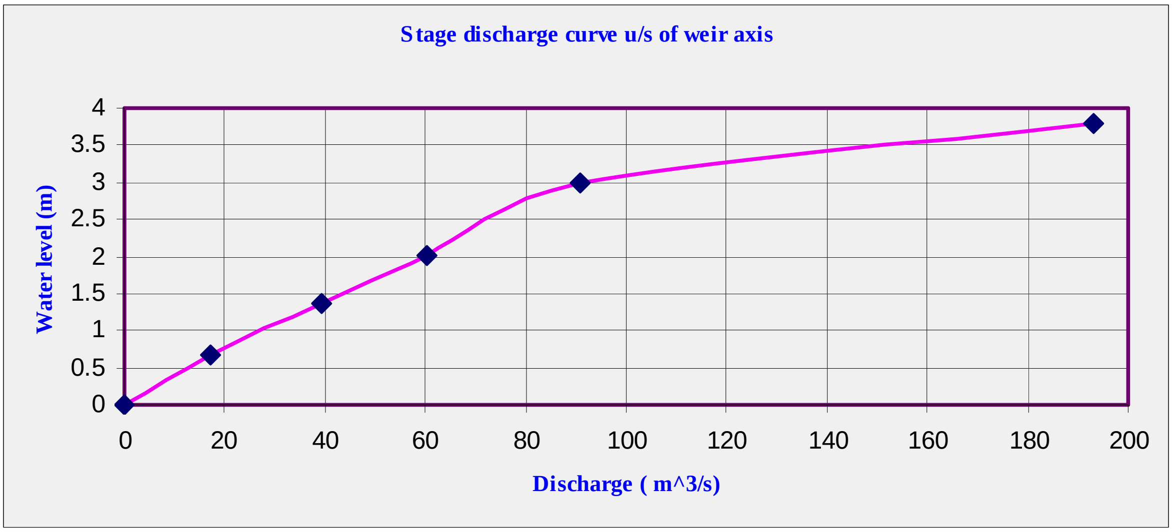


Figure 23 Stage discharge curve at upstream of the weir axis for Kulanti River

Table 12 Hydraulic parameters at downstream of the weir axis (Kulanti River)

S/N	Elevation	Stage	Wetted area	Wetted perimeter	Hydraulic radius	Velocity	River discharge
	masl	m	m^2	m	m	m/s	m^3/s
1	2170.1	0.0	0.0	0.0	0.0	0.0	0.0
2	2170.5	0.4	0.8	6.6	0.1	1.1	0.8
3	2171.1	1.0	5.2	9.6	0.5	3.0	25.7
4	2171.9	1.8	14.0	12.6	1.1	4.8	66.8
5	2172.5	2.4	31.0	27.2	1.2	4.9	150.9
6	2173.8	2.7	41.6	30.0	1.4	5.6	231.7
7	2173.5	3.4	61.4	37.2	1.7	6.2	383.6

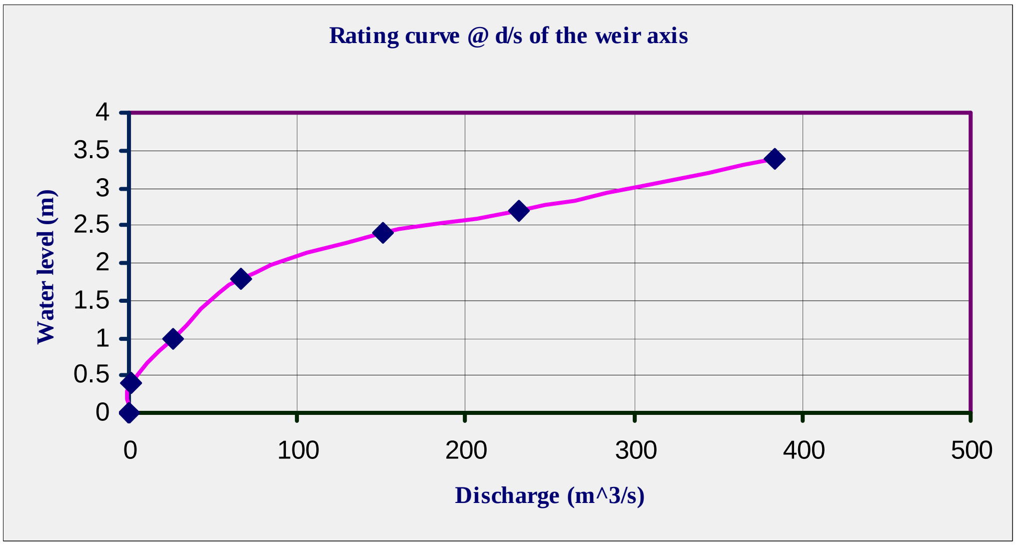


Figure 24 Stage discharge curve at downstream of the weir axis for Kulanti River

From the three stage-discharge curves, it is found that the water levels corresponding to the peak discharge 133 m^3/s of 50 years return period at the weir axis, upstream and downstream of the axis are 2.15, 3.50 and 2.25 meters respectively. With these three water levels found, it is possible to estimate the water surface slope of the river, Figure 25 ≅0.008 m/m which is important to synthesize the actual rating curve of Kulanti River at the weir axis.

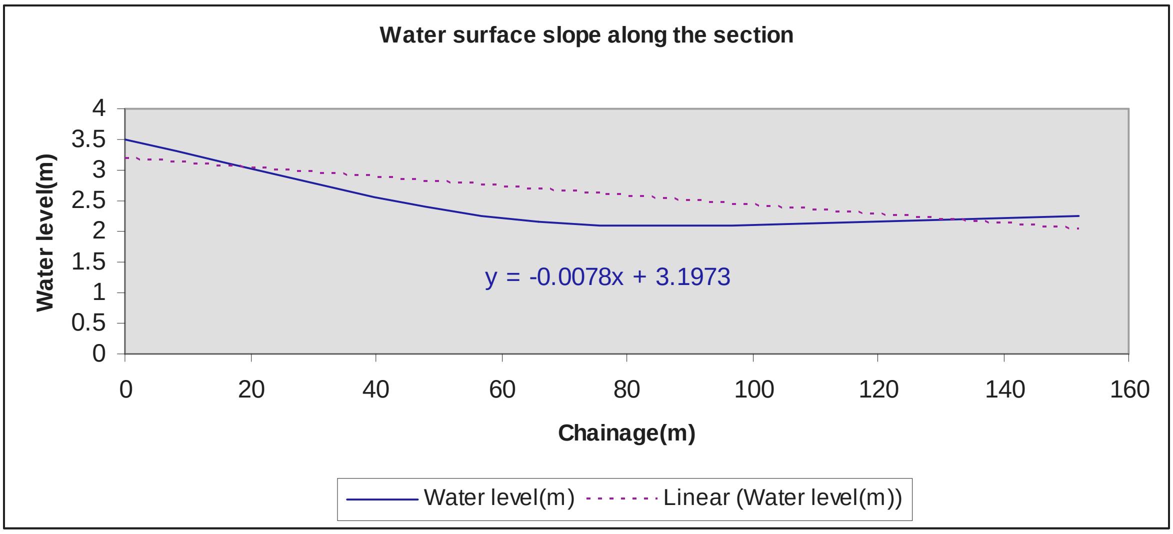


Figure 25 Water surface slope at the weir axis for Kulanti River

The water surface slope from the best fit evaluation from Figure 25 is ≅ 0.008 which is used for preparing the final rating curve at the weir axis.

Table 13 Final rating curve at the weir axis

n = 0.03			S = 0.008 (water surface slope)				
S/N	Elevation	Stage	Wetted area	Wetted perimeter	Hydraulic radius	Velocity[5]	River discharge
	masl	m	m2	m	m	m/s	m^3/s
1	2171.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2171.5	0.5	4.7	14.0	0.3	1.4	6.7
3	2171.9	0.9	7.5	15.6	0.5	1.9	13.7
4	2173.0	2.0	23.1	18.6	1.2	3.4	79.7
5	2173.7	2.7	37.2	22.2	1.7	4.2	156.3

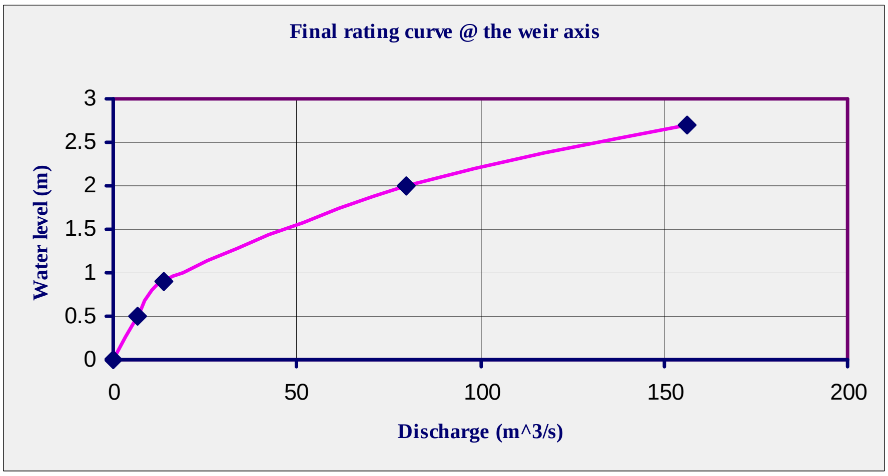


Figure 26 Final rating curve at the weir axis for Kulanti River

From the above curve, the MFL corresponding to 133 m^3/s is 2.5 m which is a key figure for the determination of height of retaining walls and allowable afflux. This concludes the hydrological analysis leading us to the hydraulic and structural analysis of the diversion weir and its components but still reference is made to this section in relation to flood levels.

9.2 Weir design

9.2.1 General

The works which are constructed at the head of the canal in order to divert the river water towards the canal so as to ensure a regulated continuous supply of silt-free water with a certain head into the canal are known as diversion works (Novak et al, 2001). The main permanent canal forming the primary part of a direct irrigation system takes-off from diversion weir or barrage. In fact these permanent canals take-off from rivers and the arrangements are so well made at their heads that a constant and a continuous water supply is ensured into the canal ,even during the periods of low flow.

[5] Velocity, V = $\frac{R^{2/3} * S^{1/2}}{n}$ is from known Manning's equation with "n" equal to 0.03 for the river bed material from the geological investigation report for Kulanti river and Q = AV

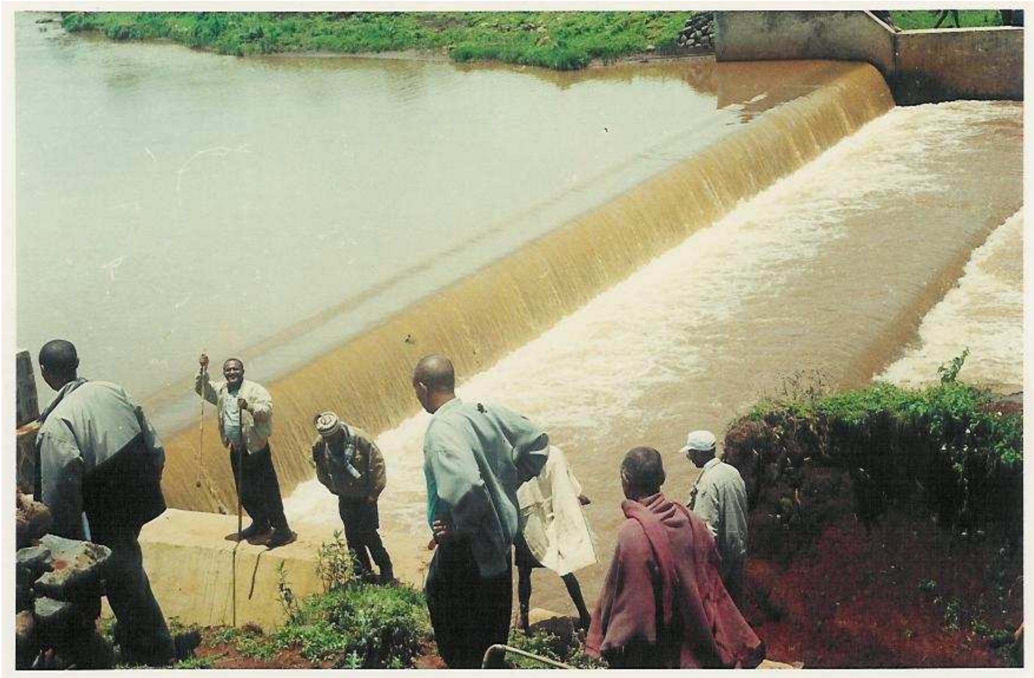


Figure 27 Kulanti diversion weir, ORDA 2003

A satisfactory hydraulic design and layout strongly depend upon accurate and complete topographic surveys of all practical sites for the diversion weir and its command area. The surveys must cover an area large enough to enable proper layout studies for geologic investigation, preparation of final grading plans, and estimates of quantities of soil and rock excavation. A topographic map with a scale of 1:1000 and a contour interval of 1 meter is satisfactory for most diversion layouts (USDA, 2007). Requirements for geologic investigation and sampling must be consistent with policy. The requirements vary according to the size and purpose of the diversion weir, economic and safety considerations, and geologic complexity of the site.

9.2.2 Factors governing the design of weirs

The following data governing the design of the weir were collected while planning Kulanti diversion weir for irrigation purposes.

i. High flood levels for the river at the weir site, 2.50 m (from section 9.1.2).
ii. High flood or maximum flood discharge for the river at the weir site, 133 m^3/s.
iii. River cross section at the weir site.
iv. The stage discharge curve for the river at the weir site, Figure 26.

All these information are obtained from topographical survey, maps of the area and by consulting hydrological departments of the localities. Parameters to be decided while designing the weir are the crest level, afflux, waterway and the discharge per meter width of weir and pond level as follows.

Hydraulic design of the weir

Important Data

Lowest river bed level = 2171.0 masl

Design flood magnitude = 133 m^3/s

Depth of flood before construction of weir = 2.50 m

High flood level before weir construction = 2173.5 masl

Main canal head regulator sill elevation = 2172.0 masl (Determined in reference to the highest point to be irrigated in the farm/ command)

Canal full supply level = 2172 + 0.3 m (where 0.3 m is the flow depth in the main canal which is found from canal cross section design to meet the peak crop water needs in the irrigated farm)

Pond level = Full supply level + regulator losses (assumed value is 20 cm)

2172.3 + 0.2 = 2172.50 masl

Taking the crest level of the weir to be at the pond level,

Height of the main weir body is = Crest elevation – River bed elevation

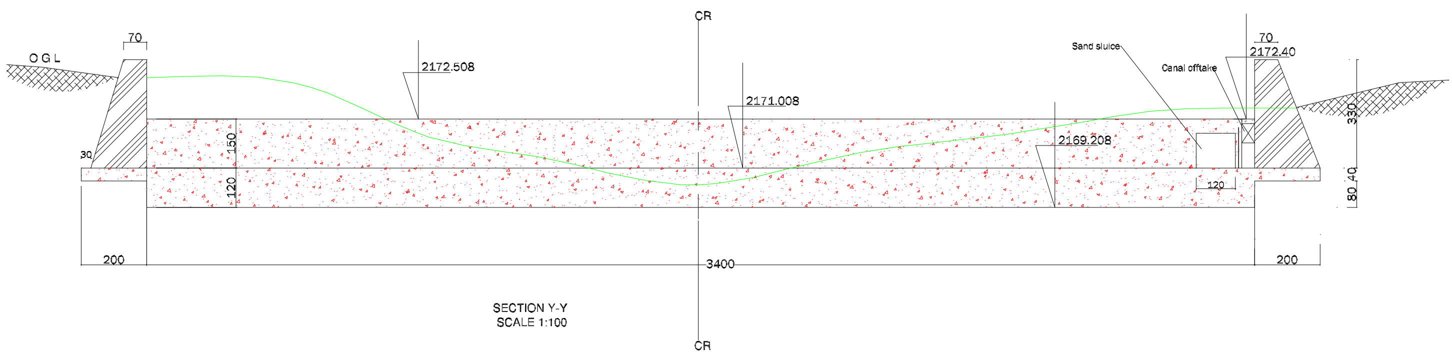
= 2172.50 – 2171.0 = 1.50 m

At a height of 1.50 m, the river cross section has got a width of 21.0 m. But its wetted perimeter from “Lacey” is calculated as

$$P = 4.84\sqrt{Q} \tag{18}$$

$$P = 4.84\sqrt{133} = 56\ m$$

However; the actual length of the weir is fixed less than this value of 56 m and more than 21.0 m due to some loosens factor (here it was assumed to be 60%). Hence the designed length of the weir is 34 m. From those important hydraulic input data; all the required parameters are evaluated following the hydraulic design aspect of weirs including scour depth, determination of upstream and downstream water levels, top and bottom width of the weir considering different loading conditions, side slope of the weir, protection against scour, and design of pervious and impervious apron using creep length theory to check its safety against uplift pressure and piping effects. Formation of the jump whether or not its length is within the location of the energy dissipation arrangements was checked. Finally the design of the weir was checked for its safety against over turning, sliding and development of negative pressures. The drawings showing the plan and sections of the weir details are attached in annex 9.2



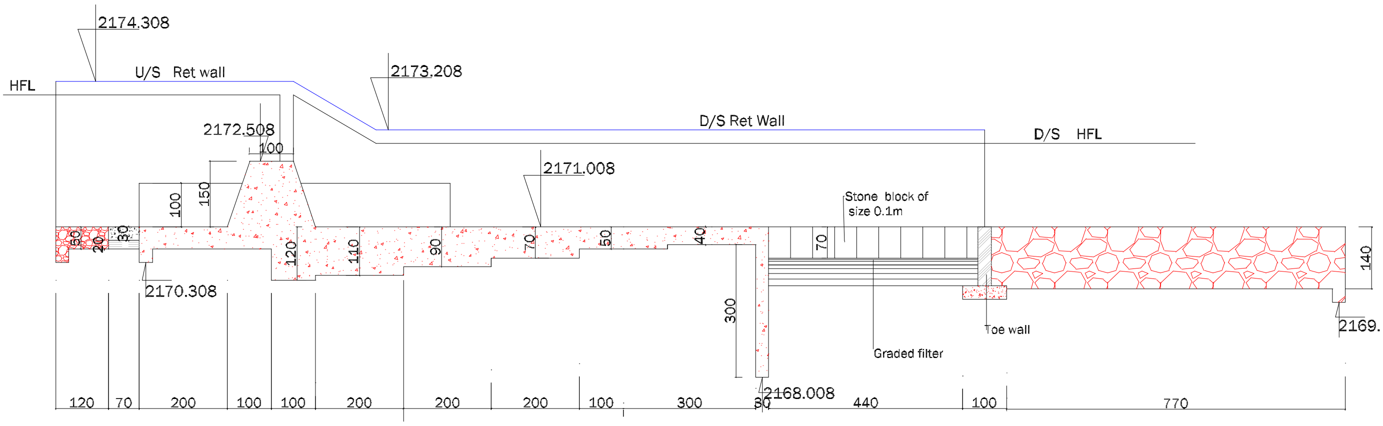


Figure 28 **Result of the Hydrologic, Hydraulic and Structural design of Kulanti diversion weir, redrawn with permission of ORDA (X – sectional and L-profiles respectively)**

10 Current crop production

10.1 Land use system

An analysis of land use/land cover offers potentials and constraints in that particular unit of land. Over al1 the type and extent of natural land cover is an indicative of the variability or uniformity of the environment. The project area lies wholly with in "Jabela lideta" peasant association and land use of the peasant association comprises 413 ha as shown below.

Table 14 **Existing Land use; Abita Agricultural Development Center 2006**

LAND USE TYPE	AREA (HA)	AREA (1%)
Cultivated Land	389	94.20
Grazing Land	17	4.10
Forest and shrubs	2	0.50
Settlement land	5	1.20
Total	413	100

Cultivated land accounts the highest proportion; 389 ha followed by grazing land 17 ha. On average each household has got about 1.6 ha of farmland and the minimum and maximum farmland holding size to each family is 0.5 and 3.0 ha respectively. Forest cover is too low and from this it can be inferred that the level of deforestation is extremely high that places the irrigation project under treat in terms of siltation and maintaining the river flow potential. Plantation of the watershed area needs crucial attention to maintain the base flow of the river which is the only source of water for irrigating the planned irrigated farm. A family cultivated land is generally made up of on average 3 plots of land each varying in size from 0.2 to 1.0 ha. According to the focus group discussion about 50 % of the families have farm lands below 1.0 ha. Generally there is shortage of farm and grazing land in the project area.

10.2 Rain fed crop production

The yearly sequence and spatial arrangement of crops in the area is mainly four dictated by factors such as prevailing rainfall distribution, farm input availability, market value of crops and others. Due to this the typical cropping pattern of the area is varying from year to year. Based on the study it is found that 40.9% teff, 28.7% millet, 13.8% maize and 11.6% noug are the dominate crops which totally account 95% of the total cultivated land and grow mainly for home consumption. The rest cultivated land is devoted for barely, potato, garlic, coffee and banana. Particularly, teff and millet are the main cereals used in making "injera“, the staple food of the area. Also millet, barely and maize are used for making the local beverage "Tella" in addition to their use in making "Injrea". Out of rain fed crops noug is an important cash crop of the area. Local farmers in the project area are practicing crop rotation to improve soil fertility and to overcome crop pests. The crop rotation trend is usually with small cereals and large stalked cereals, and cereals with vegetables.

Table 15 Typical crop rotation trend in the area for the rain fed cropping

TEFF/MILLET	⇒	MAIZE / BARELY	⇒	NOUG
Teff/ Millet	⇒	Potato	⇒	Maize /Barely
Noug	⇒	Teff/Millet	⇒	Potato

With respect to crop productivity the yield per ha for cereals is as low as 1030 kg and noug and potato yield 500 and 6000 kg per hectare respectively according the discussion with WUA leaders. The farmers in the project area get 80 percent of crop produce from cereals where as the rest are from oil crops and vegetables.

10.3 Existing irrigated cropping pattern

For Kulanti irrigation scheme, major crops under irrigation include potato, onion, barely, wheat and oat. But the feasibility study at the inception of the project showed that the crops planned under irrigation were maize, potato, banana, cabbage, onion, coffee and pepper. Due to shortage of irrigation water, the perennials could no more be irrigated but still under cultivation from rain fed water supply only. The cropping pattern of the existing system and the one initially proposed during the inception of the project is depicted as follows.

Table 16 Contrasting designed and existing cropping pattern under irrigation for Kulanti IP

PLANNED AT FEASIBILITY LEVEL			***EXISTING PATTERN***			
Crop	Wet season	Dry season	**Crop**	Wet season	Dry season	
	%	%		Area (Ha)	Crop	Area (Ha)
Maize	40	20	**Maize**	15	Potato Onion Barely oat	5 3 4.5 2.5
Wheat	20	-	**Wheat**	5	Potato	5
Potato	20	20	**Teff**	59.5	Onion Potato Barely	12 40 7.5
Pepper	-	10	**Niger seed**	2	Potato Barely	1 1
Cabbage	-	10	**Millet**	1.5	Potato Onion	1 0.5
Onion	-	20		**83**		
Coffee	10	10				
Banana	10	10				
Total	100	100				

10.4 Agronomic and cultural practices for rain fed production

Land preparation in the project area is carried out using traditional oxen drawn plough. This practice has been used since ancient times and is still in use in the area without improvement. Draught power sources of the area are oxen and horses. The frequency of ploughing varies with the types of crops grown and soil type for the irrigated crops currently. For crops such as teff, millet and vegetables, farmers used to plough up to four to five times and for others like maize, barely and noug, they plough two to three times (ORDA, 1999).

With respect to calendar of farm operation for most crops land preparation starts in the months of March and April. After land preparation, sowing is carried out from June to July for crops like teff, millet, barely and noug. Sowing is traditionally performed by broadcasting to all grain crops and farmers do not use optimum seeding rate, spacing and planting depth. After sowing the next step is weeding. The number of weeding varies from 0 to 3 according to crop type and degree of weed infestation. Generally local farmers do have moderate experience in weed controlling. Weeding is done by hand and for vegetables and maize, inter row cultivation or hoeing is practiced. The peak weeding activity in the area is carried out from late July to September for most rain fed crops.

Figure 29 Land preparation using horses, Kulanti IP

And harvesting is carried out by human labor using sickle. Then farmers pile up the harvested grain crops and after that trashing is done by spreading the harvested crops on threshing yard and then cattle are made to trample over it. Finally the grain is separated from the straw and other impurities by blowing to the air and other processes. After this the grain is stored in locally manufactured materials called “Gotta” or “Gottera”.

10.5 Extension

Extension service has been rendered to farmers in the project area since many years. So far the extension approach was training and visit system. However, the current extension approach is participatory demonstration and training system (PADETS). This system is based on demonstrating to and training of farmers in proven technologies in a participatory manner. Generally with respect to current extension activity in the area one development agent is assigned for the irrigation project besides his activities for the rain fed agriculture in the peasant association. The extension beneficiaries are grouped into different groups and each group consists of contact farmers. The agent visits each contact farmer regularly based on a schedule.

The extension support delivered to the irrigation users is not satisfactory according to the users’ responses due to the frequent turnover of the agents, their limited experience, and wide range of activities that they are supposed to handle in the peasant association and logistical shortages. However the users have long years of traditional irrigation experience and high motivation to work in their irrigation activities and hence dissemination of new technologies is possible with minimum demonstration.

10.6 Input use

Improved agricultural inputs like selected seed, fertilizer and other agro-chemicals are at low level of use in the area. For Kulanti irrigation scheme the existing irrigated crops are potato, onion, barely and oat. According to the key informants all seeds are local varieties but for some crops the application of fertilizer is exercised at a rate of 50 Kg/ha DAP and 20 Kg/ha Urea for potato and 100 Kg/ha DAP and 100 Kg/ha Urea for barely. Onion is fertilized only with animal dung. The major constraints for this limited input use are lack of credit access, fear of crop failure from natural hazards and poor economic standard of farmers to afford inputs. Despite the limited extension support given to the irrigation project the result obtained is encouraging. From the irrigation scheme the following productivity is obtained for the different crops according to the rapid diagnosis and interview made with the farmers and the extension officers: 3200 Kg/ha barely, 12,500 Kg/ha potato, 16,000 Kg/ha onion and 3200 Kg/ha oat. Regarding pesticides their application is almost non existent though crop pests cause substantial yields losses.

11 Crop water requirement

For a given cropping pattern and intensity, the irrigation requirements mm/month/ha can be determined and from this average supply of the system; the area served can be fixed. Procedures for estimating crop water and irrigation requirement are evaluated not in the context of irrigation requirements only but generally in the context of water requirement supply by rain and/or irrigation together with those other factors which give the planner the necessary information such as soil data, crop data, initial moisture content of the soil (that was found from laboratory analysis) and the effective rainfall of the area. Estimation of reference crop evapotranspiration, effective rainfall, crop water requirement, irrigation water requirement and field water supply is made with the use of CropWat 4 windows version 4.3 taking a project efficiency of 45% and decadal time step. All the results are shown in annex 11.1.

11.1 Irrigation water management and distribution

The irrigation water is diverted from a diversion weir of 34 m long and 1.50 m high made out of cyclopean concrete. The size of the main off-take at the head regulator is 30×30 cm with a bed elevation of 2172 masl as shown in the hydraulic calculation below. The regulator is a sliding gate which is designed to slide along the grooves provided with angle iron fixed on the breast walls and a handle on the top of the sliding rod. But currently the handle for rotating the intake gate is damaged and rotating the rod is possible with the use of stone. Giving special attention to farmers and their water management has proven highly instrumental in improving system performance and increasing water productivity. This attention should also be given to the farmers of Kulanti irrigation scheme to change the attitudes of those farmers who misuse the irrigation facilities like the intake gates of the head regulator.

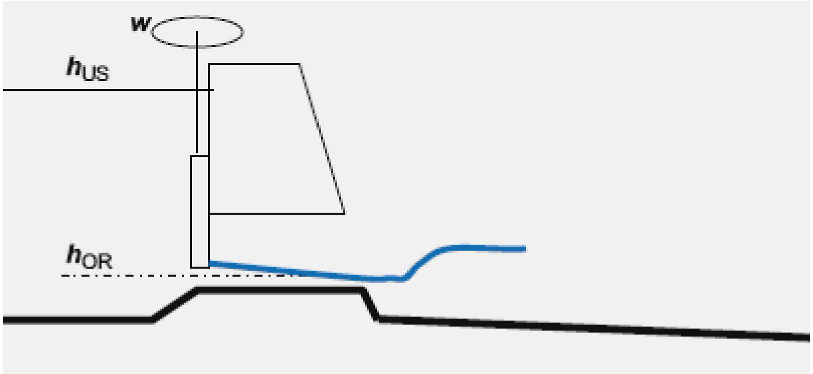


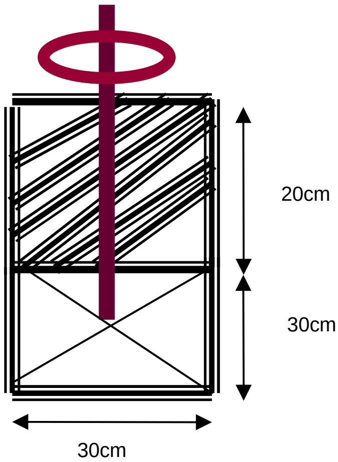
Figure 30 Longitudinal profile of the head regulator

The discharge through the opening is estimated from the orifice flow equation which is commonly used for downstream free flow conditions. Orifice type structures are often used as off-take structures from the head works to the canal system.

$$Q = CdA\sqrt{2g(h_{US} - h_{OR})} \quad (19)$$

Where

Q is the discharge through the orifice that meets the peak irrigation requirement, 69 l/s



Cd is coefficient of discharge of the orifice, ≅ 0.5,

g is acceleration due to gravity, 9.8 m/s^2

A is the cross-sectional area of the opening,

h_{US} upstream water level which is equal to the pond/crest level of the weir, 2172.5 masl,

h_{OR} water level at the center of the orifice, 2172.15 masl from calculation in section 9.2.2, and "w" is the width of rotating spindle/handle.

$$0.069 = 0.5 \times w \times h\sqrt{2 \times 9.8 \times (2172.5 - 2172.15)}$$

$1.3wh = 0.069$; This implies $wh = \dfrac{0.069}{1.3}$

The orifice is assumed to have a square cross section and hence "w" is equal to "h" and it is 23 cm from the above calculation. Take a value of 30 cm × 30 cm for the orifice opening which is neither scouring nor silting cross section. According to the irrigation scheduling found in the infrastructure design for the project (ORDA, 1999), the main canal is running under continuous operation whereas the secondary and tertiary canals are designed for rotational operation which is currently the situation. There is no any measuring structure established to measure the amount of irrigation water released except the head regulator which is designed to discharge 69 l/s of irrigation water.

The irrigation water distribution is made possible through one main canal, two secondary canals, a number of tertiary and field canals and drainage canals. There are drop structures and turnouts located along all canal systems to negotiate the natural topography with the canal profile and divide the flow in the canal system respectively. But at some drop structures the energy is not dissipated fully and the bed of the drop structure is eroded and turned into a form of shallow wells which affects the irrigation scheduling as shown in Figure 5. Division boxes or turnouts fitted with sheet metals are provided to regulate the flow and distribute the required flow to the upcoming canal system, for instance from secondary to tertiary.

Figure 31 A drop structure combined with a turnout along the tertiary canal

At some division boxes, the sheet metals are removed by some people who lack responsibility. The main canal runs as a contour canal, the secondary canals run both as a contour and side slope canal, tertiary canals run also as contour and side slope canal. On the other hand with respect to irrigation methods the widely used one is furrow for vegetable crops and flooding is used for barely and other grain crops.

Limitations of the water distribution

Two major limitations are observed in regard to water distribution in the farm. Allocating water for a group of 16 members for 24 hours and a day for a month for all the users is not a reasonable decision since the farmers at the tail end of the head work could not get the same amount of water for the same duration unlike those farmers at the head reaches of the system who have less water loss. The other problem is lack of water measuring structures that could give reliable information on the amount of water delivered to each plot so as to avoid over or under irrigation.

11.1.2 Typical design for main canal cross section

Design of the canal cross section is based on Manning's uniform flow equation and is shown below. The main data to be used in sizing the capacity of the main canal are number of irrigation hours per day, irrigation days per week and the project efficiency. From the crop water requirement planning for the project under the existing cropping pattern, the maximum demand occurs in January and it is 1.27 l/s/ha from Table 35. The current irrigable area is 83 ha and hence the maximum canal capacity should be 105 l/s which is much more than the available water resource from Kulanti River, 69 l/s. Hence the governing design factor for the main canal is from the supply side which is 69 l/s.

$$Q = AV \qquad (20)$$

Where Q is the maximum canal capacity
A is cross sectional area of the canal
V is the permissible velocity in the canal

$$V = \frac{1}{n} \times R^{2/3} \times S^{1/2} \qquad (21)$$

Where n is Manning's roughness coefficient and is equal to 0.03
R is hydraulic radius of the canal section which is the ratio of area of canal cross section to its wetted perimeter
S is the longitudinal bottom slope of the canal generally governed by the topography and the energy head required for the flow of water; 0.001.

A trapezoidal earthen main canal is designed taking into account the type of geologic formation and cost of construction. From the field assessment and soil laboratory results, canal route is dominantly silty-clay in texture and the value of the side slope "m" is approximated to be "1.0".

Table 17 Limiting side slope and flow velocity of canal for different material types, Bosch 1992

Material	Limiting side slope	Limiting velocity(m/s)
Sand	1:3	0.4
Sandy loam	1:2	0.6
Clay loam	1:1.5	0.8
Clay	1:1	1.2
Bricks	1.5:1	1.5
Concrete	1.5:1	2

Width to depth ratio (w_o/h) is equal to "1" from standard canal designs for discharge rates of 0.0-0.15m^3/s. Hence area of cross section,

$$A = \frac{1}{2} \times h \times h + w_o \times h + \frac{1}{2} \times h \times h$$

$$A = h^2 + w_o \times h$$

$$A = h^2 + h^2$$

$$A = 2h^2$$

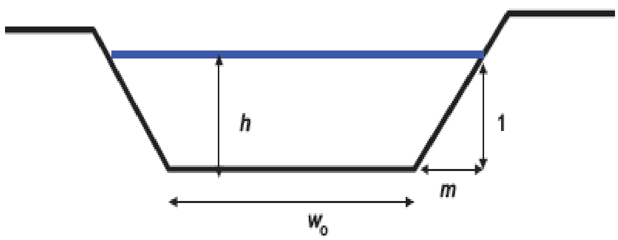
Wetted perimeter,

$$P_w = \sqrt{(mh)^2 + h^2} + w_o + \sqrt{(mh)^2 + h^2}$$

$$P_w = \sqrt{2h^2} + h + \sqrt{2h^2}$$

$$P_w = 2h\sqrt{2} + h = 3.83h$$

$$\therefore R = \frac{2h^2}{3.83h} = 0.52h$$



$$Q = \frac{1}{n} \times (0.52h)^{2/3} \times (S_0)^{1/2} \times 2h^2$$

$Q = \frac{1}{0.025} \times 0.645 h^{2/3} \times (0.001)^{1/2} \times 2h^2$ $h = (\frac{0.069}{1.632})^{3/8} = 30\ cm$

$Q = 1.632 h^{8/3} \Rightarrow h = (\frac{Q}{1.632})^{\frac{3}{8}}$

Hence the canal has the following hydraulic characteristics: $w_o = h = 30$ cm with bed slope of 0.001 and side slope "m" of 1.0. Flow velocity in the canal has to be maintained within a permissible range. In order to prevent scouring in earth canals and maintain sub critical flow; maximum velocity values should not be exceeded. Flow in irrigation canals is nearly always sub critical (deep and slow flow). At diversion, division and especially measurement structures, supercritical flow may occur and even be necessary. Minimum velocities should also be maintained in order to prevent sedimentation when the flow has a high sediment load and to limit the occurrence of water-borne diseases favored by standing or slowly moving water bodies.

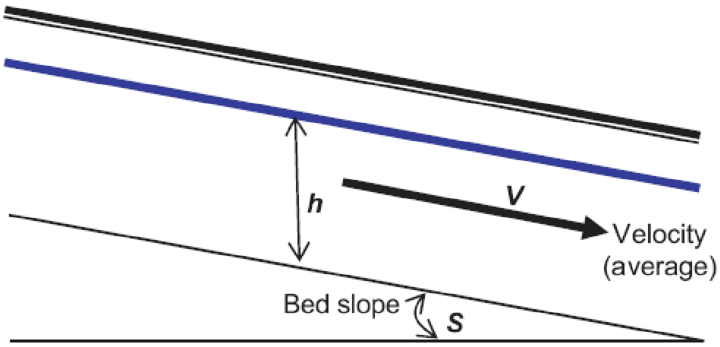


Figure 32 Schematic presentation of longitudinal canal profile

11.1.2 Typical design for a drop structure

A drop or fall structure is a regulating structure which lowers the water level along its course. The slope of the canal is usually milder than the terrain slope as a result of which the canal in cutting at its head works will soon outstrip the ground surface. In order to avoid excessive infilling the bed level of the downstream canal is lowered; the two reaches being connected by a suitable drop structure Figure 33. The drop is located so that the fillings and cuttings of the canal are equalized as much as possible. Wherever possible the drop structure may also be combined with a regulator or turnout. The location of an off-take from the canal also influences the fall site with off-takes located upstream of the fall structure.

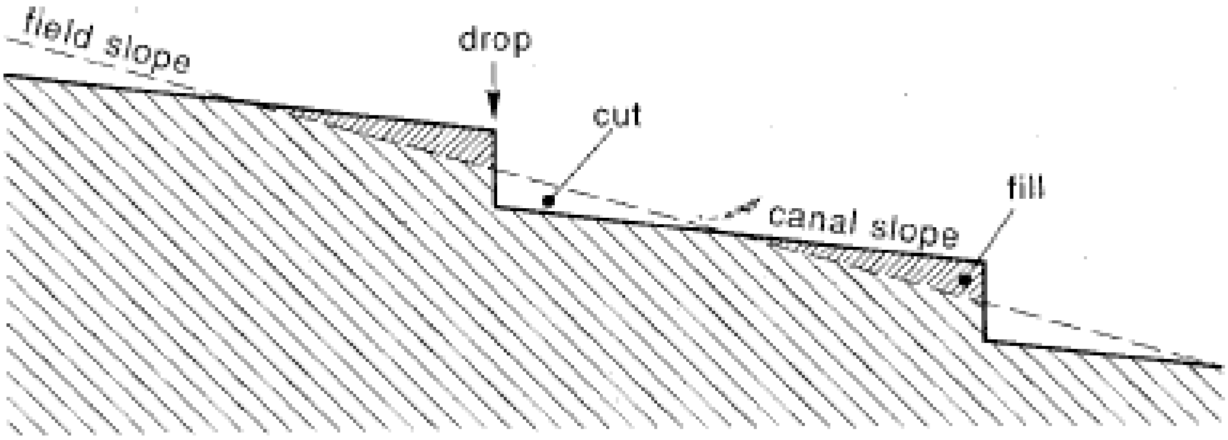


Figure 33 Longitudinal section of a canal, showing bed level drops, Bosch et al., 1992

The following data are used for the design of a typical drop structure in the main canal
Height of drop = 0.7 m (determined from topography and management and operation suitability)
Maximum discharge in the canal = 0.069 l/s
Bed width of the canal = 0.3 m
Depth of water in the canal = 0.3 m
Velocity in the canal = 0.40 m/s

$S = 1/1000$

YMGT-type drop (Japan) is designed for the project which is suitable for small canals with discharges up to 1 m^3s^{-1}. The following design criteria were used with the sill height varying from 0.06 m to 0.14 m (Novak P. et al., 2001)

$$d_c = \frac{1}{2}(E_c H_{dr})^{1/2} \qquad (22)$$

Where dc is depth of cistern
Ec is critical energy and is $1.5y_c$
Hdr is height of drop which is determined from the prevailing topography and ease of operation and is 70 cm for this typical design.

$$y_c = \left(\frac{q^2}{g}\right)^{1/3} \qquad (23)$$

Where yc is critical depth at the drop crest
q is discharge intensity, 0.069/0.3 = 0.23 $m^3s^{-1}m^{-1}$

Hence yc is found to be 0.18 m from equation (22) and dc is 0.22 m from equation (21).

$$L_c = 2.5Ld \qquad (24)$$

Where Lc is length of cistern
Ld is $L_{d1} + L_{d2}$

$$L_{d1}/E_c = 1.155\left[\left(p'/E_c\right) + 0.33\right]^{1/2} \qquad (25)$$

Hence L_{d1} is 0.5 m taking an assumed value of p' 10 cm

$$L_{d2} = (D_2 + d_c)\cot\alpha \qquad (26)$$

Where D_2 is depth of flow in the canal and here it is equal to D_1 which is 0.3 m. Hence L_{d2} is estimated from equation (25) to be 0.2 m. Therefore Ld is equal to L_{d1}+L_{d2} and is 0.7 m which results in a cistern length, Lc of 1.75 m with in which the whole energy had to be dissipated before getting into the canal downstream.

$$Cot\alpha = {y_c}/{L_{d1}} \qquad (27)$$

Summary of drop parameters

D_1	0.3 m which is the flow depth in the canal and equal to D_2
E_l	0.31 m which is $D_1 + {V_a}^2/2g$
Ec	0.27 m
y_c	0.18 m
Hdr	0.7 m (determined from site conditions)
dc	0.22 m
Lc	1.75 m which the most important parameter in dissipating the energy

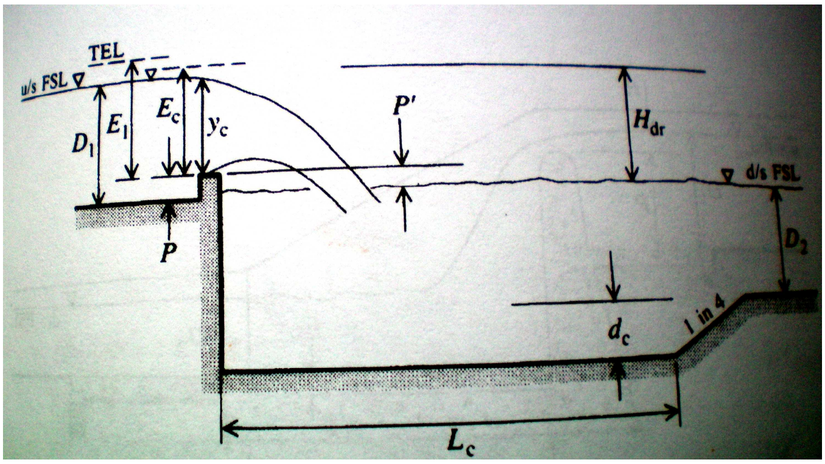


Figure 34 Typical cross sectional profile of a drop structure showing the different design parameters

12 Organizational condition at project level

To ease allocation of water to farmers and to mobilize farmers at time of diversion and for canal clearing the users have established water users committee and the committee is strong enough to carry out all the required activities. Putting farmers in charge of water development and management has proved effective to achieve efficient and sustainable water management systems and to increase water productivity. This is evident in the transfer of management of irrigation systems to the immediate beneficiaries and through the formation of water users association, where users assume direct responsibilities in operation and maintenance of the irrigation system. The members of the WUA are currently 135 out of which 21 are female headed and the rest are male headed house holds. To be registered as a member, he or she has to pay 30 birr[6].

The main duties of the association are water distribution management, maintenance, planning of cropping seasons, establishing relations to share water resources with downstream and upstream users and dealing with cooperative societies for marketing and input supply and addressing market issues when the prices are less than expected. The major achievement made by the WUA management is conflict resolution with the upstream water users which was even beyond the district administration and about to lead to loss of life and bloodshed especially the role played by the chairman was profound in addressing the problem.

The association had an office and regular monthly meetings and other administrative issues are held there. The chairman, the vice chairman, the cashier, secretary and two members form the management committee of the WUA. The major role played by the users according to the focus group discussion in the establishment of the project is explained in terms of their involvement during the feasibility study and the construction phase. They provided free labor during the survey (soil sample digging, carrying thedolite for topographic survey) and in the collection and supply of local construction material, canal excavation and watering of the concrete works during the execution of the project.

Figure 35 Office of WUA for Kulanti irrigation project

[6] Local currency and equql to 0.07€ as of August 2008

13 Performance gaps

There are four potential kinds of performance gaps that can occur with irrigation systems (Douglas et al, 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. The main canal breaching at around cattle crossings caused poor performance of the main canal and due to lowering of the bed level from the design, some drop structures are abandoned from use due to their higher elevation.

Figure 36 Canal breaching a long the main canal for Kulanti irrigation project

The normal solution to technology performance gaps is to change the type, design or condition of physical infrastructure and hence this canal breaching needs to be rehabilitated through the use of masonry or concrete lining which calls for the support of the government as it requires substantial financial investment and is beyond the capacity of the beneficiaries.

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. The major performance gap in terms of management procedures for Kulanti irrigation project is the deviation of the existing cropping pattern from the designed one and malfunctioning of the sand sluice that impacted the efficiency of the water supply to the main canal.

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 which can be called a gap in achievement. A problem in this aspect in Kulanti irrigation scheme is the expansion of the irrigated area to 83 ha beyond the planned 65 ha which resulted in moisture stress of crops and thereby yield reduction. This was due to lack of follow up from district relevant experts until farmers get used to implementation procedures according to the design in the feasibility study. To improve the irrigation efficiency there need to be lining requirement at some reaches of the canal system and there by increase water productivity.

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. There are no adverse negative impacts due to Kulanti irrigation project where as the positive impacts can be qualified quantitatively in terms of the number of children sent to school and the number of houses constructed out of corrugated iron sheets replacing thatched houses and qualitatively the improvement in household diet.

14 Cost benefit analysis

Cost-Benefit Analysis (CBA) estimates and totals up the equivalent money value of the benefits and costs to the community of projects to establish whether they are worthwhile. To show the feasibility of Kulanti IP, it is tried to workout the total cost of production for the irrigated farm and compare its benefits under the existing cropping pattern. This analysis is made from the point of view of a non-economist and is to give an impression on the major costs and the benefits.

Production costs

According to the focus group discussion the main production costs are the cost of agronomic practices and external inputs as shown below. The local wage price is used to convert man days into monetary terms which is 8 birr per day.

Table 18 Cost of agronomic practices according to WUA leaders

Crop	Activity	Man days/Ha	Area covered (Ha)	Total man days	Local Wage (Birr/day)	Total Birr
Onion	Ploughing	12	15.5	186	8	1488
	Sowing	60	15.5	930	8	7440
	Hoeing	120	15.5	1860	8	14880
	Harvesting	60	15.5	930	8	7440
Potato	Ploughing	16	52	832	8	6656
	Sowing	16	52	832	8	6656
	Hoeing	32	52	1664	8	13312
	Harvesting	40	52	2080	8	16640
Barely	Ploughing	40	13	520	8	4160
	Sowing	20	13	260	8	2080
	Harvesting	20	13	260	8	2080
	Threshing	12	13	56	8	448
Oat	Ploughing	40	2.5	100	8	800
	Sowing	20	2.5	50	8	400
	Harvesting	20	2.5	50	8	400
	Threshing	12	2.5	30	8	240
						85,120

Table 19 Costs of external inputs according to WUA leaders

<table>
<tr><td>Type of crop</td><td>Seed rate (kg/ha)</td><td>Area covered (Ha)</td><td>Total (Kg)</td><td>Unit price (Birr/kg)</td><td>Total price (Birr)</td><td>Fertilizer rate (Kg/ha)</td><td>Area covered (Ha)</td><td>Total (Kg)</td><td>Unit Price (Birr)</td><td>Total price (Birr)</td></tr>
<tr><td>Onion</td><td>800</td><td>15.5</td><td>12,400</td><td>1.6</td><td>19,840</td><td colspan="4">Fertilized with animal manure</td><td>0.000</td></tr>
<tr><td>Potato</td><td>6000</td><td>52</td><td>312,000</td><td>1.8</td><td>561,600</td><td>70</td><td>52</td><td>3640</td><td>3.2</td><td>11648</td></tr>
<tr><td>Barely</td><td>400</td><td>13</td><td>5200</td><td>3.5</td><td>18,200</td><td>200</td><td>13</td><td>2600</td><td>3.2</td><td>8320</td></tr>
<tr><td>Oat</td><td>400</td><td>2.5</td><td>1000</td><td>4.3</td><td>4300</td><td>200</td><td>2.5</td><td>500</td><td>3.2</td><td>1600</td></tr>
<tr><td>Total</td><td colspan="4"></td><td>603,940</td><td colspan="4"></td><td>21,568</td></tr>
<tr><td rowspan="2">Type of crop</td><td colspan="5">Irrigation</td><td colspan="5">Maintenance</td></tr>
<tr><td>Man days/ha</td><td>Area (Ha)</td><td>Total man days</td><td>Man days rate (Birr)</td><td>Total birr</td><td>Birr/ha</td><td>Area (Ha)</td><td>Total (Birr)</td><td colspan="2" rowspan="6"></td></tr>
<tr><td>Onion</td><td>40</td><td>15.5</td><td>620</td><td>8</td><td>4,960</td><td>8</td><td>15.5</td><td>124</td></tr>
<tr><td>Potato</td><td>24</td><td>52</td><td>1,248</td><td>8</td><td>9,984</td><td>8</td><td>52</td><td>416</td></tr>
<tr><td>Barely</td><td>16</td><td>13</td><td>208</td><td>8</td><td>1,664</td><td>8</td><td>13</td><td>104</td></tr>
<tr><td>Oat</td><td>16</td><td>2.5</td><td>40</td><td>8</td><td>320</td><td>8</td><td>2.5</td><td>20</td></tr>
<tr><td>Total</td><td></td><td></td><td></td><td></td><td>16,928</td><td></td><td></td><td>664</td></tr>
<tr><td colspan="4">Total production cost is</td><td>85,129</td><td>603,940</td><td>21,568</td><td>16,928</td><td>664</td><td colspan="2">728,229</td></tr>
</table>

When a project is constructed, certain amount of money has to be invested and for Kulanti IP the following capital investment was made and besides this capital investment there are recurring annual expenditures on maintenance and operation of the project as shown above that amounts to birr **728,229.**

Table 20 Initial capital investment cost for Kulanti IP, ORDA 1999

COMPONENT	COST (ETHIOPIAN BIRR)
Construction of diversion weir	580,000
Construction of irrigation infrastructure	400,000
Study and design cost	50,000
Total capital investment	**1,030,000**

The capital cost has to be recovered during a certain fixed period (equal to the life of the structure or less than that for conservative designs) a long with a certain minimum interest rate called minimum attractive rate of return. From depreciation and compound rate interest calculations, it can be stated that the capital recovery factor ,i.e. the factor by which the capital investment should be multiplied in order to get the equivalent annual recovery cost is given by (Kumar,1989).

$$CRF = \frac{\left[(1+i)^N\right]}{\left[(1+i)^N - 1\right]} \qquad (28)$$

Where CRF is capital recovery factor
i is interest rate per annum and is equal to 3%
N is service life of the diversion weir and the irrigation infrastructure and is 30 years.

$$CRF = \frac{\left[(1+0.03)^{30}\right]}{\left[(1+0.03)^{30} - 1\right]} = 0.05$$

Hence annual recovery cost is 1,030,000×0.05 = 51,500 Birr and when added to the annual production cost of **728,229** gives a total annual cost of ***779,729*** birr.

Benefits

Mainly the benefits are from the sale of the produces from the irrigation project.

Table 21 Project benefits

Crop type	Area covered (Ha)	Productivity (Kg/ ha)	Total (Kg)	Farm gate price (Birr/kg)	Total (Birr[7])
Potato	52	12,500	650,000	1.8	1,170,000
Onion	15.5	16,000	248,000	1.6	396,800
Barely	13	3200	41,600	3.5	145,600
Oat	2.5	3200	8000	3.5	28,000
	83				**1,740,400**

[7] Birr is Ethiopian currency and is equal to 0.07€ as of august 2008

Hence benefit cost ratio is $\frac{1,740,400}{779,729} \cong 2.23$ which is higher than the threshold value and hence the project is feasible.

15 Summary and conclusion

The planning of an irrigation system needs time and wide ranges of experts and a strong commitment from the government side to implement the designed irrigation system on the ground particularly the management procedures in terms of the cropping pattern and irrigation scheduling. For Kulanti irrigation scheme, the designed cropping pattern is almost violated and changed which implies a change in the irrigation scheduling of the project. To make the irrigation system function to meet the planned objective, support is required from the side of the government until the WUA is strong enough to take up the management aspects and establish minimum running financial capacity. If the project is required to run by the users themselves soon after completion of the construction, the chances of deviating from the planned cropping pattern, management and operation is inevitable.

This is the case for Kulanti irrigation project, for instance in terms of change in cropping pattern, expansion of the irrigated land from 65 ha to 83 ha and increasing the irrigation hours from 18 to 24 hours a day. In terms of operating the intake and the sand sluice gates it needs technical know how so that effort must be made from the government side to transfer skill to the users which needs time for the first few years of operation until the farmers fully take over the operation capacity. For Kulanti irrigation scheme, the sand sluice is already non-functional and the handle for the intake gate is damaged due to absence of initial operational skill transferred from the side of the government. Rather the users were responsible to run the operation up on completion of the construction of the diversion weir and the irrigation infrastructure which is not reasonable.

The detailed investigation of the upstream and downstream water users must be made as it is the major cause of conflict since water is becoming a scarce resource once people realized the use of irrigation water. If not, the constructed diversion weir and irrigation system will function under capacity due to upstream abstraction and on the other side; if there are users from downstream there is a danger of destruction of the system particularly the intake and turnout gates which are easy for destruction. Hence a detailed assessment is required before decision is made about the location of the diversion weir a long the course of the river. A serious conflict event which was about to lead to bloodshed had occurred for Kulanti irrigation project due to the fact that upstream users abstracted the water by installation of a sheet metal as a diversion structure.

When planning diversion systems watershed planning must be an integral part of the planning because of its contribution in increasing the recharge of the river and minimizing sediment generated from the catchment. For the planning of Kulanti diversion irrigation project the limitations that are observed during the study are lack of environmental impact assessment study, absence of catchment treatment plans and from the technical design aspect, there are no flow measuring structures which are the key to the success of irrigation water management. If the amount of water supplied to each plot is not measured and does not meet requirements due to over irrigation or under irrigation, the consequences may result in environmental problems from salinity and reduction of crop yields from moisture stress respectively. Hence a comprehensive planning of diversion systems for irrigation purposes must address technical engineering, environmental, social and more importantly agronomic and organizational aspects at users' level. To rearticulate, the technology of irrigation is more complex than many appreciate. It is important that the scope of irrigation science not be 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 in a holistic manner.

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APPENDICES

Appendix 2.5.1 Thermal zones of Ethiopia

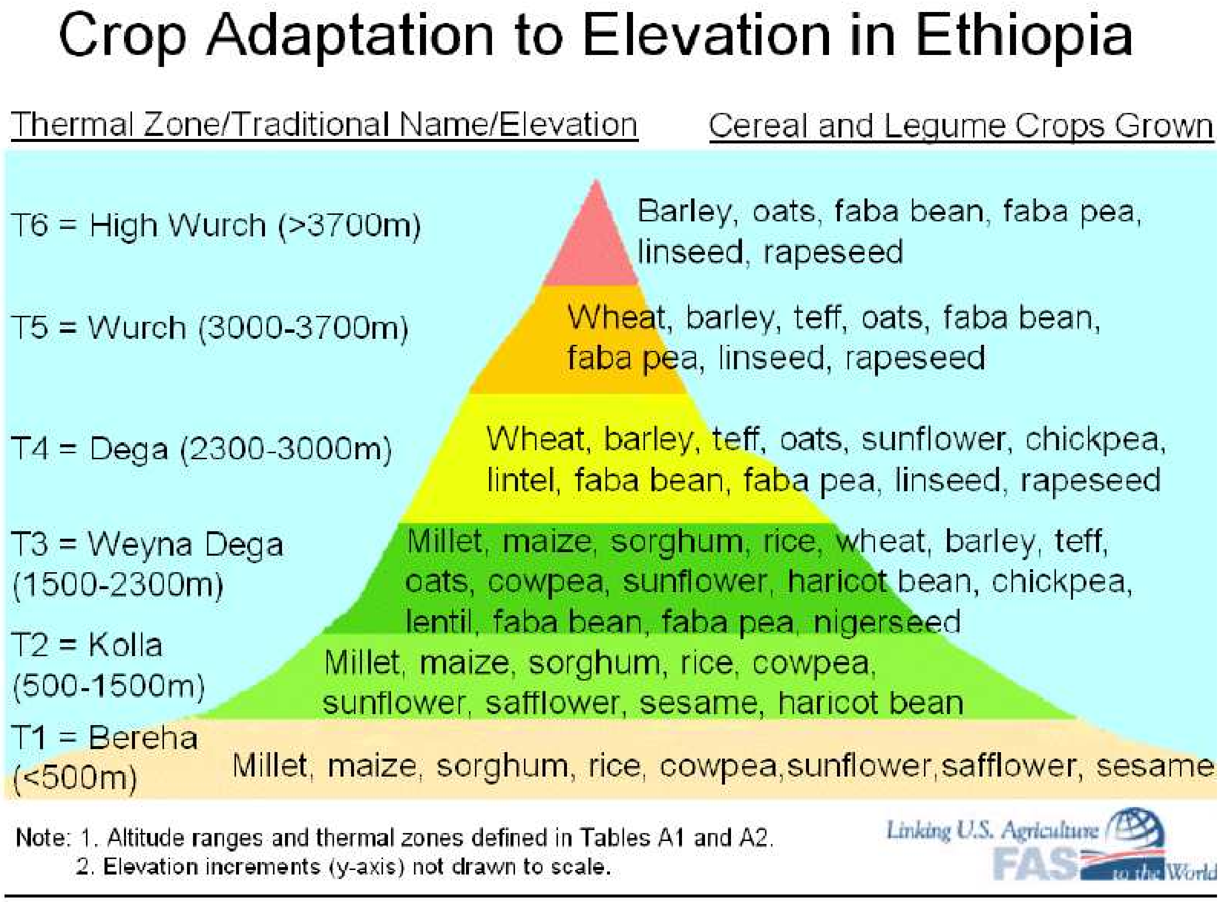

Figure 37 The different agro climatic zones and corresponding cultivated crops in Ethiopia, Westphal et al., 1975

Annex 7.1 Meteorological data

Table 22 Maximum and minimum temperature for the study area (NMSA Bahir Dar Branch, 2008)

Station Name	Class	Zone	Woreda	Altitude	Latitude	Longitude
Dangila	1	Awi	Dangila	2116.000	11.434	36.846

Dangila monthly maximum temperature(Degree Celsius)

Month/year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1997	25.5	27.2	27.6	26.7	24.1	23.4	21.7	22.4	24.2	23.3	24.3	25.4
1998	25.3	*	28.3	29.8	26.0	23.9	20.7	21.1	23.2	23.7	24.6	25.3
1999	25.7	28.6	27.6	28.1	25.0	23.7	20.6	21.5	22.7	22.4	24.2	24.8
2000	26.3	27.6	28.7	25.6	25.5	22.8	21.7	21.4	23.2	22.9	23.9	24.8
2001	25.3	27.7	27.2	28.5	26.0	22.4	21.5	21.4	23.2	23.7	24.3	25.6
2002	26.0	28.0	27.9	29.2	28.1	23.4	23.4	22.2	23.0	*	*	*
2003	26.8	28.3	29.1	29.5	29.6	24.2	21.8	22.4	23.5	24.6	25.6	26.1
2004	27.0	27.6	29.1	27.5	27.9	23.3	22.6	22.6	23.3	23.9	25.2	26.1
2005	26.3	29.7	29.1	29.6	*	24.6	21.1	22.2	23.3	23.6	25.2	26.2
2006	27.0	28.5	28.7	28.3	25.1	23.8	22.3	22.1	23.0	23.7	25.0	5.7

Dangila monthly minimum temperature(Degree Celsius)

Month/Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1997	3.5	4.3	8.9	9.3	10.8	9.9	10.7	10.3	9.7	9.2	7.2	4.8
1998	3.7	*	11.0	11.7	13.2	12.4	13.0	12.8	11.9	10.9	6.6	3.7
1999	4.4	6.9	5.1	10.5	11.1	10.3	10.9	10.7	9.5	9.6	5.0	3.9
2000	3.5	4.0	5.3	8.2	9.6	8.9	9.2	9.0	8.6	8.5	5.3	5.3
2001	3.4	7.1	8.4	11.6	11.9	12.6	12.8	12.9	11.3	11.4	7.4	6.3
2002	5.9	7.7	9.8	10.7	12.1	13.1	12.7	12.2	11.1	10.1	7.4	4.6
2003	4.1	7.9	10.2	9.5	12.4	12.8	13.1	13.0	11.7	10.0	8.2	5.0
2004	5.1	6.6	8.7	11.6	11.2	12.7	12.2	12.3	11.3	9.3	8.4	5.7
2005	4.5	7.4	9.4	12.3	*	12.6	12.7	12.3	12.0	11.0	6.8	3.8
2006	5.8	8.0	8.4	10.5	12.7	12.5	12.8	12.8	12.1	11.3	8.1	1.6

Table 23 Monthly average relative humidity and wind speed values for the study area (NMSA Bahir Dar Branch, 2008)

Station Name	Class	Zone	Woreda	Altitude	Latitude	Longitude
Dangila	1	Awi	Dangila	2116.000	11.434	36.846

Monthly Relative Humidity (%)

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	67.7	66.3	64.8	66.4	74.8	86.4	91.9	90.8	87.7	82.5	76.5	74.9
1996	65.5	61.1	64.5	67.8	84.5	88.1	90.4	90.0	88.0	84.5	81.3	76.2
1997	66.9	67.9	69.0	73.4	83.0	85.7	90.6	89.6	85.2	87.4	83.6	74.2
2001	49.8	52.3	40.9	41.0	58.3	78.0	82.1	83.5	77.5	76.1	63.0	55.6
2002	50.8	40.8	38.0	34.8	37.8	75.3	77.7	81.9	77.1	72.9	62.7	53.2
2003	43.5	43.5	41.4	31.6	36.8	76.0	82.2	83.1	77.6	69.5	60.4	51.3
2004	47.6	41.5	33.5	45.2	49.5	74.7	79.8	81.6	77.6	70.0	62.5	54.0
2005	47.6	37.5	40.2	34.8	*	73.1	82.5	82.1	78.0	74.5	59.2	45.8
2006	26.1	39.3	34.0	39.7	67.4	74.8	79.4	82.1	77.6	55.4	43.5	9.2

Monthly average wind speed values

Year/Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1997	1.0	1.2	1.3	1.4	1.3	1.2	1.2	1.1	1.2	0.8	0.8	0.9
1998	1.1	1.2	1.3	1.3	1.3	1.3	1.2	1.2	0.9	0.9	0.7	0.9
1999	0.9	1.0	1.2	1.4	1.3	1.2	1.2	1.2	1.0	0.8	0.7	0.7
2000	0.9	1.0	1.2	1.1	1.2	*	1.1	1.1	0.9	0.8	0.7	0.7
2001	0.9	1.0	1.0	1.1	1.2	1.0	1.1	1.0	0.9	0.8	0.7	0.8
2002	0.9	0.9	1.1	1.2	1.4	1.2	1.1	1.0	0.8	0.7	0.6	0.7
2003	0.8	0.9	0.9	1.2	1.3	1.1	1.0	1.1	0.8	0.7	0.7	0.8
2004	0.8	1.0	1.0	1.0	1.2	1.0	1.1	1.1	0.9	0.7	0.6	0.7
2005	0.8	0.8	0.9	1.0	*	1.2	0.9	0.8	0.8	0.7	0.5	0.5
2006	0.7	0.9	1.0	1.0	0.9	0.9	0.9	0.9	0.6	0.6	0.5	0.1

Table 24 Monthly average sunshine hours and rainfall for the study area (NMSA Bahir Dar Branch, 2008)

Station Name	Class	Zone	Woreda	Altitude	Latitude	Longitude						
Dangila	1	Awi	Dangila	2116.000	11.434	36.846						
Sunshine Hours(Hrs)												
Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997	8.5	8.7	6.9	7.1	5.9	5.6	4.3	4.5	7.6	5.7	8.1	9.3
1998	9.1	8.8	8.1	9.1	7.6	7.4	3.3	3.8	6.2	6.2	8.5	9.7
1999	9.1	10.2	10.1	8.4	8.0	7.1	3.5	4.4	6.6	5.5	9.4	9.1
2000	9.6	9.4	8.9	6.4	8.0	*	4.8	4.2	6.3	5.3	8.5	8.8
2001	9.7	9.0	7.4	9.4	7.5	4.9	3.8	3.5	7.2	6.4	8.6	8.3
2002	8.7	9.2	8.8	9.4	9.7	6.6	6.4	5.0	6.6	6.9	8.5	8.9
2003	9.7	8.5	7.3	9.7	9.2	6.1	4.0	4.0	5.7	7.6	8.6	9.5
2004	9.5	9.3	8.8	7.5	9.6	5.5	5.4	4.4	6.0	7.2	7.7	8.5
2005	8.8	9.5	7.5	7.8	*	6.2	3.6	4.5	6.0	6.3	8.6	9.4
2006	9.0	9.1	8.2	8.6	6.3	6.5	4.3	3.4	4.7	5.4	8.7	1.7
Monthly average rainfall(mm)												
Year/Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1997	0.0	0.0	35.7	52.4	235.0	240.1	351.4	369.7	180.4	163.6	90.5	3.4
1998	0.0	0.0	22.7	13.9	186.1	307.5	282.3	333.6	254.2	148.3	6.4	0.0
1999	2.0	0.0	0.8	36.3	243.7	280.8	388.8	370.8	329.5	263.9	35.8	7.8
2000	0.0	7.1	7.5	77.0	135.3	*	313.0	436.1	237.8	265.3	70.0	2.5
2001	0.0	0.0	14.5	13.9	157.3	321.3	380.0	253.3	150.3	97.6	3.3	0.0
2002	0.0	*	11.9	14.8	52.1	278.8	298.9	345.7	182.7	123.0	30.3	2.0
2003	0.0	4.5	7.5	2.2	23.1	330.6	338.9	279.0	301.9	26.8	55.0	0.0
2004	0.0	9.1	2.3	90.5	60.7	230.5	487.9	363.8	266.6	94.7	21.0	0.0
2005	4.0	0.5	29.2	7.4	*	270.9	303.5	344.7	*	*	*	*
2006	2.9	0.0	0.0	47.9	258.9	339.7	440.2	392.9	227.6	186.8	6.8	3.0

Annex 7.2 laboratory analysis results on soils of the irrigated farm

Table 25 Summary of laboratory analysis of soil samples of the irrigated farm

APR- 2008

BOWRD

Soil Mechanics Laboratory

No	Project	Test P.No	Depth (cm)	PH	EC (µs/cm)
1	Irrigation Suitability	2	12	6.2	1.5
2	"	1	22	5.3	1.6
3	"	2	22	6.8	1.2
4	"	1	Top Soil	5.9	1.4
5	"	1	Layer-2	6.4	1.5
6	"	2	13 (top soil)	6.1	1.3

Tested by ______

Date ______

Cheeked by ______

Date ______

Approved by ______

Date 24/04/2008

Amhara National Regional State * Water Resources Development Bureau

Pit 1
Layer 3
Depth 22 cm

PH 2 → Top soil (layer 0)
Depth = 13 cm

PIT 1
Top soil
Depth 18 cm

BoWRD

Soil Mechanics Laboratory

Grain Size Analysis (Hydrometer Method)

Project :

Location : Top Soil

Depth: 18cm

Sample No :

Test Pit No : 01

M ass of dry soil sample **(M)=200g**

Mass of fraction passing **2mm sieve=190g**

Mass of dry soil sample taken from minus **2mm=50g**

Gs of soil particles of minus 75 micron=**2.69**

Meniscus correction (Cm) =**0.5**

Hydrometer No. =**152H**

Date	Elapsed Time,t (min)	Hydrometer Reading (Rh')	Temprature (^{0}C)	Composite Correction -+C	Rh=Rh'+ Cm	Effective Depth,h(cm)	$(h/t)^{1/2}$	Factor	Particle size,D(mm)	R=Rh-+C	%Finer(N') based on M_d	%Finer(N) based on whole $N=N'*M_1/M$
13/8/2000	0.5	53	20.5	-5	53.5	10.07	4.49	1402.00	0.0699	48.00	96.00	95.65
	1	50	20.5	-5	50.5	10.27	3.20	1402.00	0.0449	45.00	90.00	89.67
	2	49	20.5	-5	49.5	10.57	2.30	1402.00	0.0322	44.00	88.00	87.68
	5	48	20.5	-5	48.5	10.97	1.48	1402.00	0.0208	43.00	86.00	85.69
	10	47	20.5	-5	47.5	11.37	1.07	1402.00	0.0149	42.00	84.00	83.69
	15	46	20.5	-5	46.5	11.57	0.88	1402.00	0.0123	41.00	82.00	81.70
	30	45	21	-5	43	11.97	0.63	1402.00	0.0089	40.00	80.00	79.71
	60	44	22	-5	42	12.47	0.46	1402.00	0.0064	39.00	78.00	77.72
	120	42	24	-5	41	12.97	0.33	1384.00	0.0046	37.00	74.00	73.73
	240	40	26	-5	39	13.47	0.24	1351.00	0.0032	35.00	70.00	69.74
	480	38	25	-4	38.5	14.07	0.17	1305.00	0.0022	34.00	68.00	67.75
	1440	36	20	-5	36.5	14.77	0.10	1402.00	0.0014	31.00	62.00	61.77

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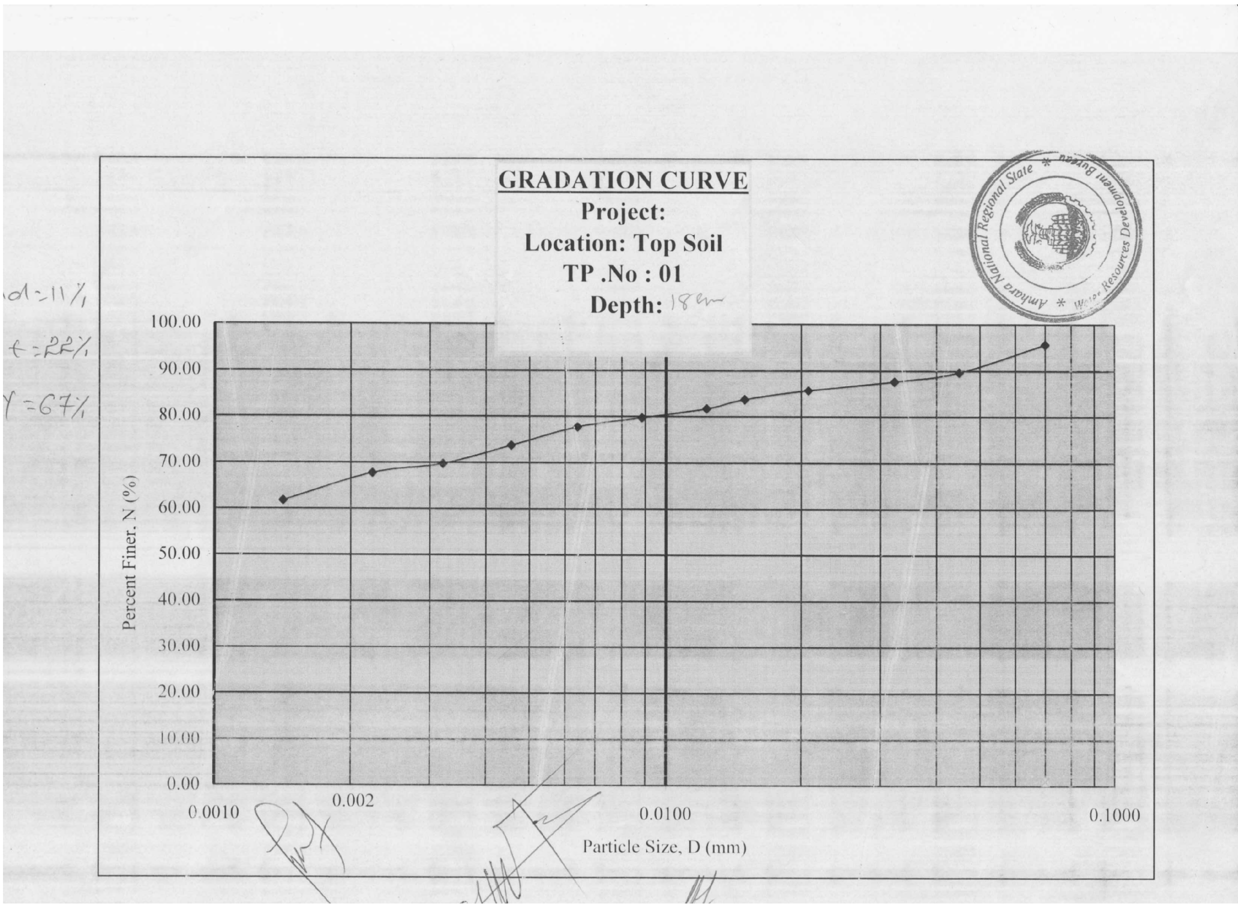
Page 1


GRADATION CURVE
Project:
Location: Top Soil
TP .No : 01
Depth:
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Percent Finer, N (%)
0.0010
0.002
0.0100
0.1000
Particle Size, D (mm)

BoWRD
Soil Mechanics Laboratory
Grain Size Analysis (Hydrometer Method)

Project :

Location : Layer -2

Depth:

Sample No :

Test Pit No : 01

M ass of dry soil sample **(M)=200g**

Mass of fraction passing **2mm sieve=190g**

Mass of dry soil sample taken from minus **2mm=50g**

Gs of soil particles of minus 75 micron=**2.69**

Meniscus correction (Cm) =**0.5**

Hydrometer No. =**152H**

Date	Elapsed Time,t (min)	Hydrometer Reading (Rh')	Temprature (^{o}C)	Composite Correction -+C	Rh=Rh'+Cm	Effective Depth,h(cm)	$(h/t)^{1/2}$	Factor	Particle size,D(mm)	R=Rh-+C	%Finer(N') based on M_d	%Finer(N) based on whole $N=N'*M_1/M$
13/8/2000	0.5	55	20.5	-5	55.5	10.07	4.49	1402.00	0.0699	50.00	100.00	99.64
	1	52	20.5	-5	52.5	10.27	3.20	1402.00	0.0449	47.00	94.00	93.66
	2	50	20.5	-5	50.5	10.57	2.30	1402.00	0.0322	45.00	90.00	89.67
	5	48	20.5	-5	48.5	10.97	1.48	1402.00	0.0208	43.00	86.00	85.69
	10	46	20.5	-5	46.5	11.37	1.07	1402.00	0.0149	41.00	82.00	81.70
	15	45	20.5	-5	45.5	11.57	0.88	1402.00	0.0123	40.00	80.00	79.71
	30	44	21	-5	43	11.97	0.63	1402.00	0.0089	39.00	78.00	77.72
	60	41	22	-5	42	12.47	0.46	1402.00	0.0064	36.00	72.00	71.74
	120	39	24	-5	41	12.97	0.33	1384.00	0.0046	34.00	68.00	67.75
	240	37	26	-5	39	13.47	0.24	1351.00	0.0032	32.00	64.00	63.77
	480	36	25	-5	36.5	14.07	0.17	1305.00	0.0022	31.00	62.00	61.77
	1440	34	20	-5	34.5	14.77	0.10	1402.00	0.0014	29.00	58.00	57.79

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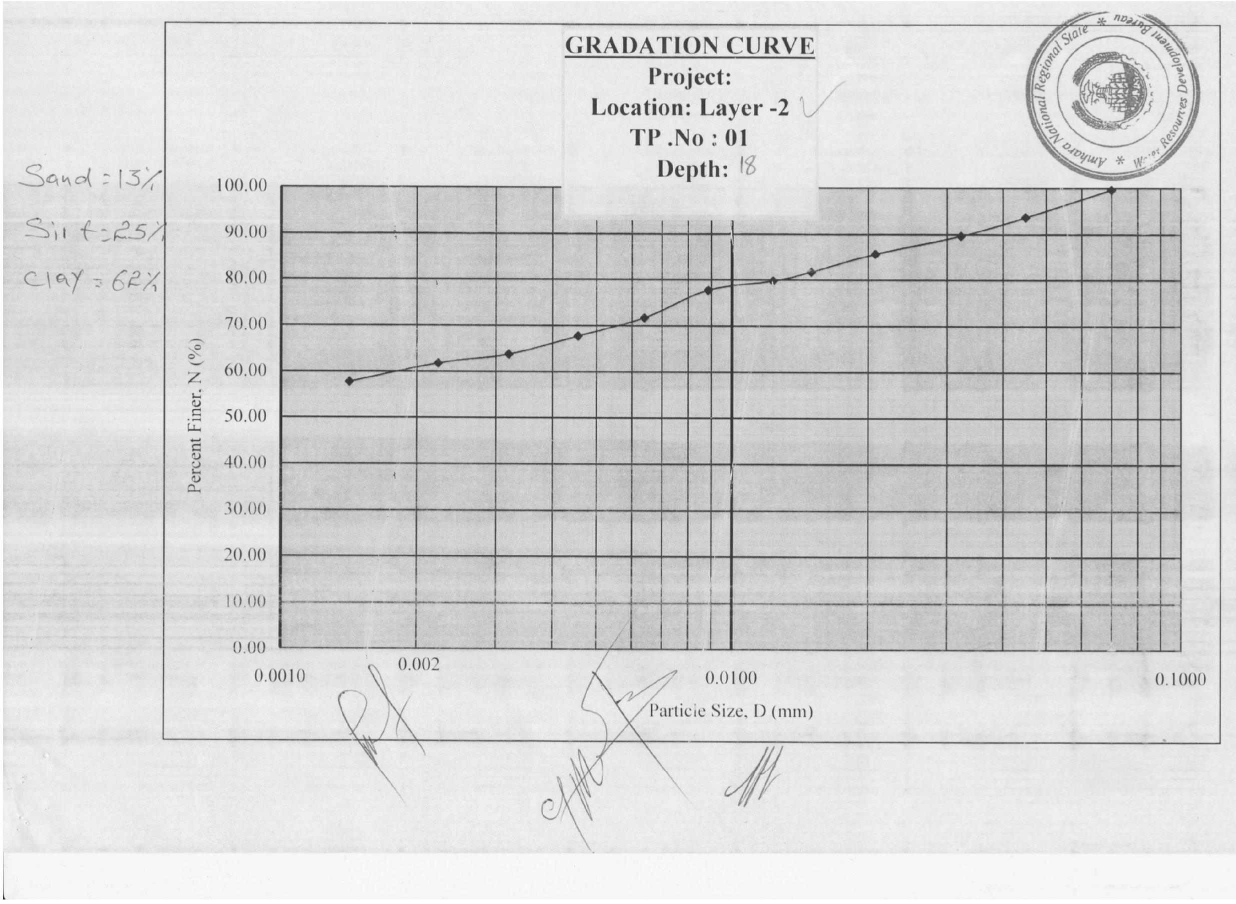
Page 1



Sand = 13%
Silt = 25%
Clay = 62%
GRADATION CURVE
Project:
Location: Layer -2
TP .No : 01
Depth: 18
Percent Finer, N (%)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.0010
0.002
0.0100
0.1000
Particle Size, D (mm)
Amhara National Regional State * Water Resources Development Bureau *

BoWRD

Soil Mechanics Laboratory

Grain Size Analysis (Hydrometer Method)

Project :

Location : Layer -3

Depth: 22cm

Sample No :

Test Pit No : 01

M ass of dry soil sample **(M)=200g**

Mass of fraction passing **2mm sieve=190g**

Mass of dry soil sample taken from minus **2mm=50g**

Gs of soil particles of minus 75 micron=**2.63**

Meniscus correction (Cm) =**0.5**

Hydrometer No. =**152H**

Date	Elapsed Time,t (min)	Hydrometer Reading (Rh')	Temprature (^{O}C)	Composite Correction -+C	Rh=Rh'+ Cm	Effective Depth,h(cm)	$(h/t)^{1/2}$	Factor	Particle size,D(mm)	R=Rh-+C	%Finer(N') based on M_d	%Finer(N) based on whole $N=N'*M_1/M$
13/8/2000	0.5	54	20.5	-5	54.5	10.07	4.49	1402.00	0.0699	49.00	98.00	97.64
	1	50	20.5	-5	50.5	10.27	3.20	1402.00	0.0449	45.00	90.00	89.67
	2	49	20.5	-5	49.5	10.57	2.30	1402.00	0.0322	44.00	88.00	87.68
	5	45	20.5	-5	45.5	10.97	1.48	1402.00	0.0208	40.00	80.00	79.71
	10	44	20.5	-5	44.5	11.37	1.07	1402.00	0.0149	39.00	78.00	77.72
	15	42	20.5	-5	42.5	11.57	0.88	1402.00	0.0123	37.00	74.00	73.73
	30	40	21	-5	43	11.97	0.63	1402.00	0.0089	35.00	70.00	69.74
	60	38	22	-5	42	12.47	0.46	1402.00	0.0064	33.00	66.00	65.76
	120	36	24	-5	41	12.97	0.33	1384.00	0.0046	31.00	62.00	61.77
	240	35	26	-5	39	13.47	0.24	1351.00	0.0032	30.00	60.00	59.78
	480	32	25	-4	32.5	14.07	0.17	1305.00	0.0022	28.00	56.00	55.80
	1440	32	20	-5	32.5	14.77	0.10	1402.00	0.0014	27.00	54.00	53.80

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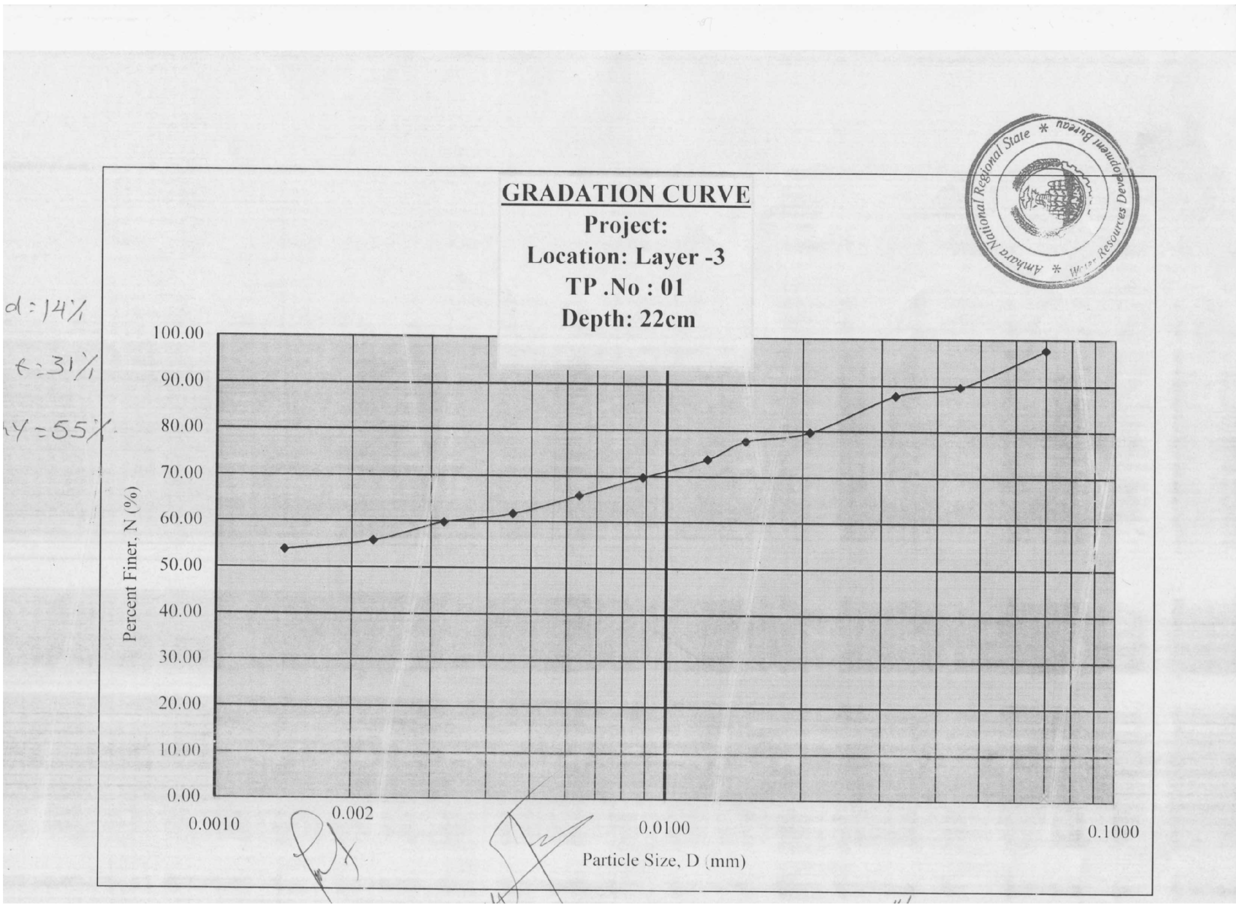
Page 1



d=14%
t=31%
Y=55%
GRADATION CURVE
Project:
Location: Layer -3
TP .No : 01
Depth: 22cm
Percent Finer, N (%)
Particle Size, D (mm)

BoWRD

Soil Mechanics Laboratory

Grain Size Analysis (Hydrometer Method)

Amhara National Regional State * Water Resources Development Bureau

Project :

Location : Top Soil(Layer - 0)

Depth: 13cm

Sample No :

Test Pit No : 02

M ass of dry soil sample **(M)=200g**

Mass of fraction passing **2mm sieve=191g**

Mass of dry soil sample taken from minus **2mm=50g**

Gs of soil particles of minus 75 micron=**2.65**

Meniscus correction (Cm) =**0.5**

Hydrometer No. =**152H**

Date	Elapsed Time,t (min)	Hydrometer Reading (Rh')	Temprature (°C)	Composite Correction -+C	Rh=Rh'+ Cm	Effective Depth,h(cm)	$(h/t)^{1/2}$	Factor	Particle size,D(mm)	R=Rh-+C	%Finer(N') based on M_d	%Finer(N) based on whole $N=N'*M_1/M$
13/8/2000	0.5	55	20.5	-5	55.5	10.07	4.49	1402.00	0.0699	50.00	100.00	99.64
	1	50	20.5	-5	50.5	10.27	3.20	1402.00	0.0449	45.00	90.00	89.67
	2	48	20.5	-5	48.5	10.57	2.30	1402.00	0.0322	43.00	86.00	85.69
	5	46	20.5	-5	46.5	10.97	1.48	1402.00	0.0208	41.00	82.00	81.70
	10	44	20.5	-5	44.5	11.37	1.07	1402.00	0.0149	39.00	78.00	77.72
	15	40	20.5	-5	40.5	11.57	0.88	1402.00	0.0123	35.00	70.00	69.74
	30	38	21	-5	43	11.97	0.63	1402.00	0.0089	33.00	66.00	65.76
	60	36	22	-5	42	12.47	0.46	1402.00	0.0064	31.00	62.00	61.77
	120	34	24	-5	41	12.97	0.33	1384.00	0.0046	29.00	58.00	57.79
	240	32	26	-5	39	13.47	0.24	1351.00	0.0032	27.00	54.00	53.80
	480	30	25	-5	30.5	14.07	0.17	1305.00	0.0022	25.00	50.00	49.82
	1440	28	20	-5	28.5	14.77	0.10	1402.00	0.0014	23.00	46.00	45.83

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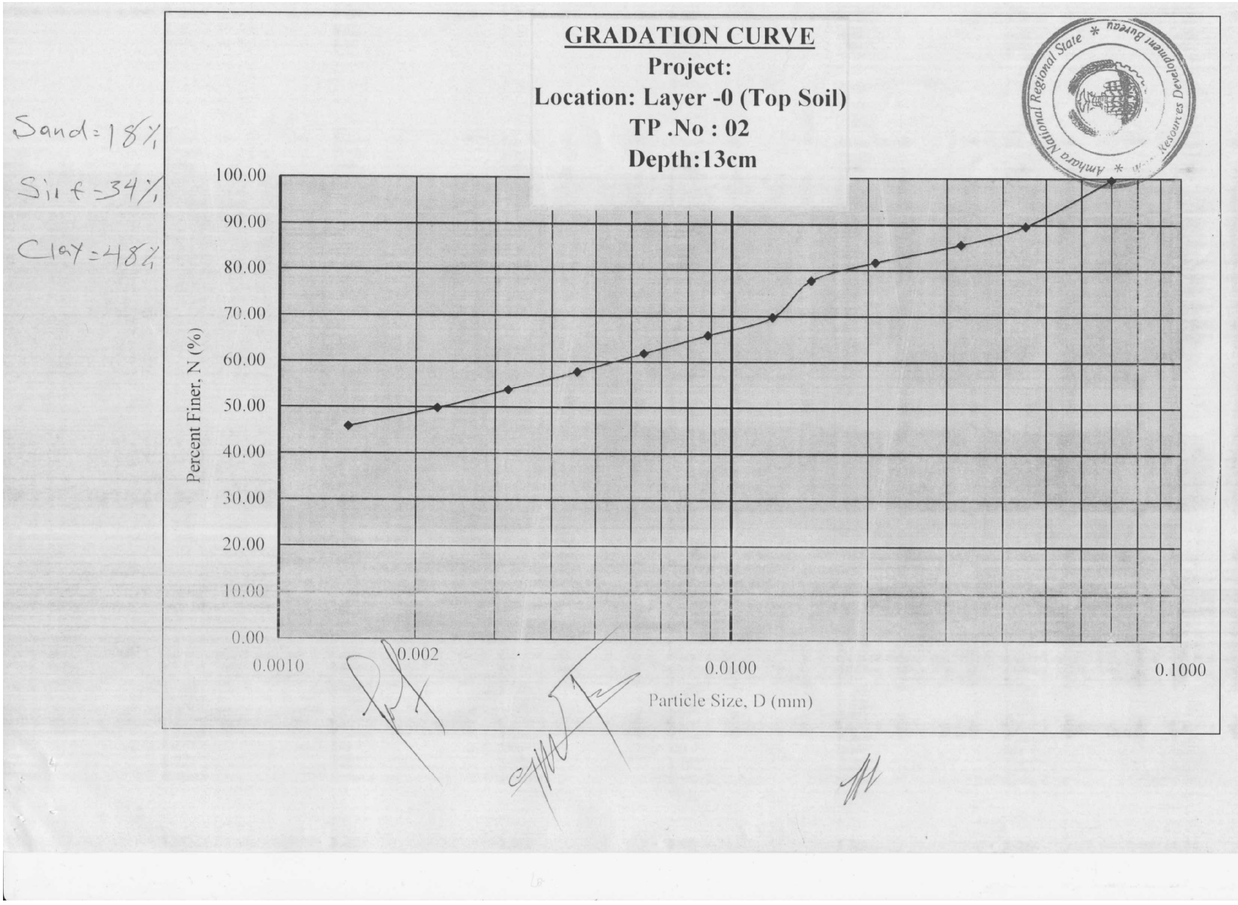
Page 1


GRADATION CURVE
Project:
Location: Layer -0 (Top Soil)
TP .No : 02
Depth:13cm
Sand=18%
Silt=34%
Clay=48%
Percent Finer, N (%)
Particle Size, D (mm)
0.0010
0.002
0.0100
0.1000
Amhara National Regional State

BoWRD

Soil Mechanics Laboratory

Grain Size Analysis (Hydrometer Method)

Project :

Location : Layer -1

Depth: 12cm

Sample No :

Test Pit No 02

M ass of dry soil sample **(M)=200g**

Mass of fraction passing **2mm sieve=195g**

Mass of dry soil sample taken from minus **2mm=50g**

Gs of soil particles of minus 75 micron=**2.69**

Meniscus correction (Cm) =**0.5**

Hydrometer No. =**152H**

Date	Elapsed Time,t (min)	Hydrometer Reading (Rh')	Temprature (°C)	Composite Correction -+C	Rh=Rh'+ Cm	Effective Depth,h(cm)	$(h/t)^{1/2}$	Factor	Particle size,D(mm)	R=Rh-+C	%Finer(N') based on M_d	%Finer(N) based on whole $N=N'*M_1/M$
13/8/2000	0.5	53	20.5	-5	53.5	10.07	4.49	1402.00	0.0699	48.00	96.00	95.65
	1	52	20.5	-5	52.5	10.27	3.20	1402.00	0.0449	47.00	94.00	93.66
	2	51	20.5	-5	51.5	10.57	2.30	1402.00	0.0322	46.00	92.00	91.66
	5	49	20.5	-5	49.5	10.97	1.48	1402.00	0.0208	44.00	88.00	87.68
	10	47	20.5	-5	47.5	11.37	1.07	1402.00	0.0149	42.00	84.00	83.69
	15	45	20.5	-5	45.5	11.57	0.88	1402.00	0.0123	40.00	80.00	79.71
	30	44	21	-5	43	11.97	0.63	1402.00	0.0089	39.00	78.00	77.72
	60	43	22	-5	42	12.47	0.46	1402.00	0.0064	38.00	76.00	75.72
	120	42	24	-5	41	12.97	0.33	1384.00	0.0046	37.00	74.00	73.73
	240	40	26	-5	39	13.47	0.24	1351.00	0.0032	35.00	70.00	69.74
	480	38	25	-4	38.5	14.07	0.17	1305.00	0.0022	34.00	68.00	67.75
	1440	37	20	-5	37.5	14.77	0.10	1402.00	0.0014	32.00	64.00	63.77

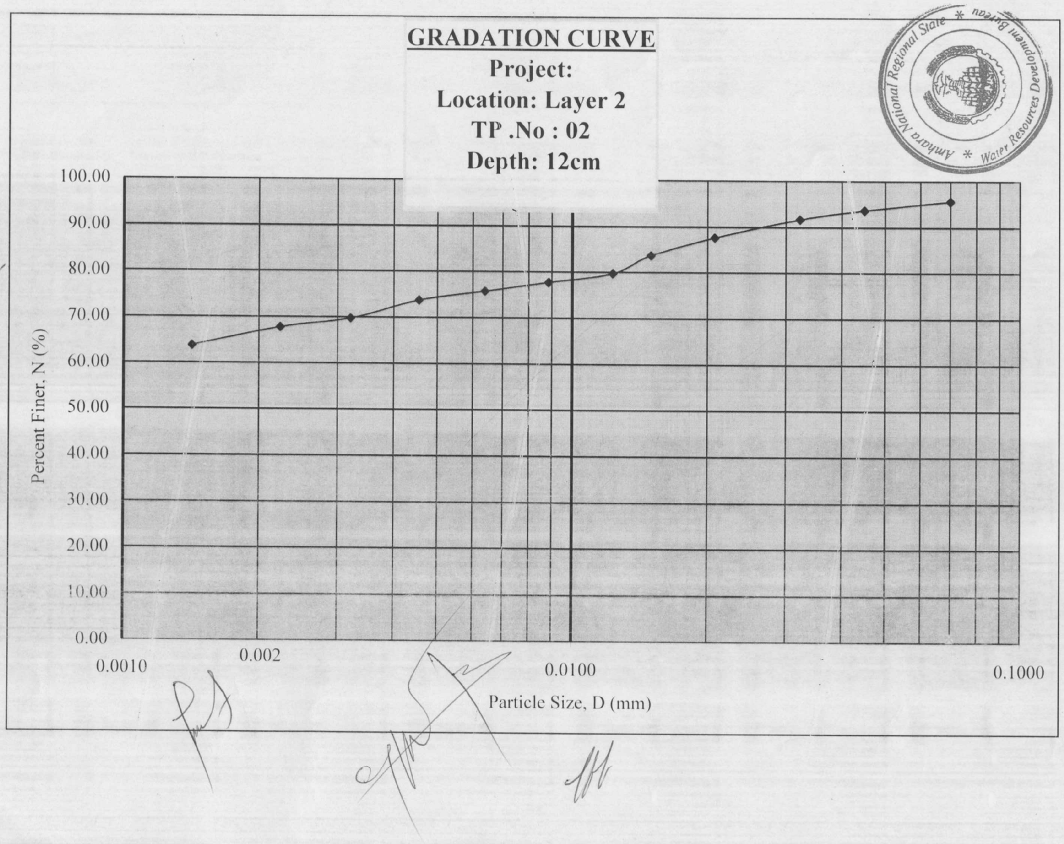
Tested by　　　　Cheked by　　　　Approved by

Page 1

Sand = 21%

Silt = 11%

Clay = 68%



BoWRD
Soil Mechanics Laboratory
Grain Size Analysis (Hydrometer Method)

Project :
Location : Layer -2
Depth: 22cm
Sample No :
Test Pit No : 02

M ass of dry soil sample **(M)=200g**
Mass of fraction passing **2mm sieve=190g**
Mass of dry soil sample taken from minus **2mm=50g**
Gs of soil particles of minus 75 micron=**2.69**

Meniscus correction (Cm) =**0.5**
Hydrometer No. =**152H**

Date	Elapsed Time,t (min)	Hydrometer Reading (Rh')	Temprature (^{O}C)	Composite Correction -+C	Rh=Rh'+ Cm	Effective Depth,h(cm)	$(h/t)^{1/2}$	Factor	Particle size,D(mm)	R=Rh-+C	%Finer(N') based on M_d	%Finer(N) based on whole $N=N'*M_1/M$
13/8/2000	0.5	51	20.5	-5	51.5	10.07	4.49	1402.00	0.0699	46.00	92.00	91.66
	1	48	20.5	-5	48.5	10.27	3.20	1402.00	0.0449	43.00	86.00	85.69
	2	44	20.5	-5	44.5	10.57	2.30	1402.00	0.0322	39.00	78.00	77.72
	5	41	20.5	-5	41.5	10.97	1.48	1402.00	0.0208	36.00	72.00	71.74
	10	39	20.5	-5	39.5	11.37	1.07	1402.00	0.0149	34.00	68.00	67.75
	15	37	20.5	-5	37.5	11.57	0.88	1402.00	0.0123	32.00	64.00	63.77
	30	33	21	-5	43	11.97	0.63	1402.00	0.0089	28.00	56.00	55.80
	60	31	22	-5	42	12.47	0.46	1402.00	0.0064	26.00	52.00	51.81
	120	30	24	-5	41	12.97	0.33	1384.00	0.0046	25.00	50.00	49.82
	240	28	26	-5	39	13.47	0.24	1351.00	0.0032	23.00	46.00	45.83
	480	27	25	-4	27.5	14.07	0.17	1305.00	0.0022	23.00	46.00	45.83
	1440	26	20	-5	26.5	14.77	0.10	1402.00	0.0014	21.00	42.00	41.85

Tested by   Cheked by   Approved by

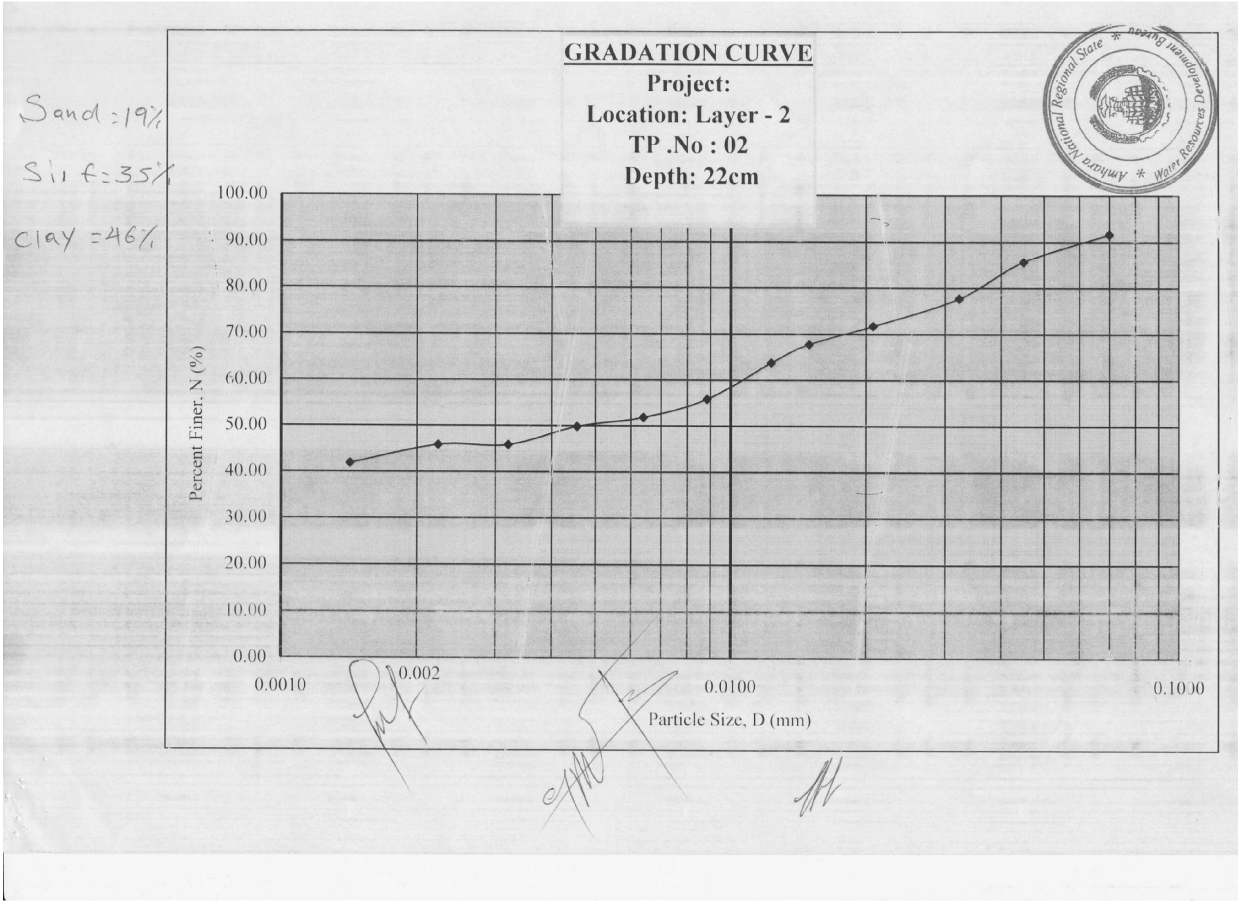


Figure 38 Soil textural analysis by using hydrometric method for different samples

Table 26 Soil moisture content analysis for the irrigated farm

Project: Kulanti irrigation
Location:
Test Pit No : 1&2

Test Pit.No	Cor. cut. No	Wt.of cut. + wet soil	Wt. of cut. + dry soil	Wt. of cut.	Wt. of dry soil	Wt. Of water	Moisture content	Remark
1(0-3ocm)	5	259.42	225.12	103.88	121.24	34.30	28.29	
1(30-60cm)	4	261.81	219.87	103.49	116.38	41.94	36.04	
1(0-30cm)	8◄	234.16	205.69	100.50	105.19	28.47	27.07	not full
1(30-60cm)	7	269.39	225.54	103.05	122.49	43.85	35.80	
2(0-30cm)	A	245.05	208.55	81.44	127.11	36.50	28.72	
2(30-60cm)	B	252.81	212.85	81.60	131.25	39.96	30.45	
2(0-30cm)	C◄	174.94	155.37	81.09	74.28	19.57	26.35	not full
2(30-60cm)	D	257.87	215.04	81.46	133.58	42.83	32.06	

Tested by_ Checked by App.by_

Amhara National Regional State * Water Resources Development Bureau *

Annex 7.3 Salinity limits for soils

Table 27 Approximate limits of salinity classes, USDA 1954

Class	Salt (%)	ECe(mmhos/cm)
Class 0-free	0-0.15	0-4
Class 1-affected	0.15-0.35	4-8
Class 2-moderatley affected	0.35-0.65	8-15
Class 3- Strongly affected	>0.65	>15

Annex 9.1 Tables and graphs that help in the hydrological analysis

Table 28 Frequency Factor for the Gumbel distribution

Sample size n	Return period or Recurrence Interval								
	5	10	15	20	25	50	75	100	1000
15	0.967	1.703	2.117	2.410	2.632	3.321	3.721	4.004	6.265
20	0.919	1.625	2.023	2.302	2.517	3.179	3.563	3.836	6.006
25	0.888	1.575	1.963	2.235	2.444	3.088	3.463	3.729	5.842
30	0.866	1.541	1.922	2.188	2.393	3.026	3.393	3.653	5.727
35	0.851	1.516	1.891	2.152	2.354	2.979	3.341	3.598	
40	0.838	1.495	1.866	2.126	2.326	2.943	3.301	3.554	5.576
45	0.829	1.478	1.847	2.104	2.303	2.913	3.268	3.520	
50	0.820	1.466	1.831	2.086	2.283	2.889	3.241	3.491	5.478
55	0.813	1.455	1.818	2.071	2.267	2.869	3.219	3.467	
60	0.807	1.446	1.806	2.059	2.253	2.852	3.200	3.4465	
65	0.801	1.437	1.796	2.048	2.241	2.837	3.183	3.429	
70	0.797	1.430	1.788	2.038	2.230	2.824	3.169	3.413	5.359
75	0.792	1.423	1.780	2.029	2.220	2.812	3.155	3.400	
80	0.788	1.417	1.773	2.020	2.212	2.802	3.145	3.387	
85	0.785	1.413	1.767	2.013	2.205	2.793	3.135	3.376	
90	0.782	1.409	1.762	2.007	2.198	2.785	3.125	3.367	
95	0.780	1.405	1.757	2.002	2.193	2.777	3.116	3.357	
100	0.779	1.401	1.752	1.998	2.187	2.770	3.109	3.349	5.261
∞	0.719	1.305	1.635	1.866	2.044	2.592	2.911	3.137	4.936

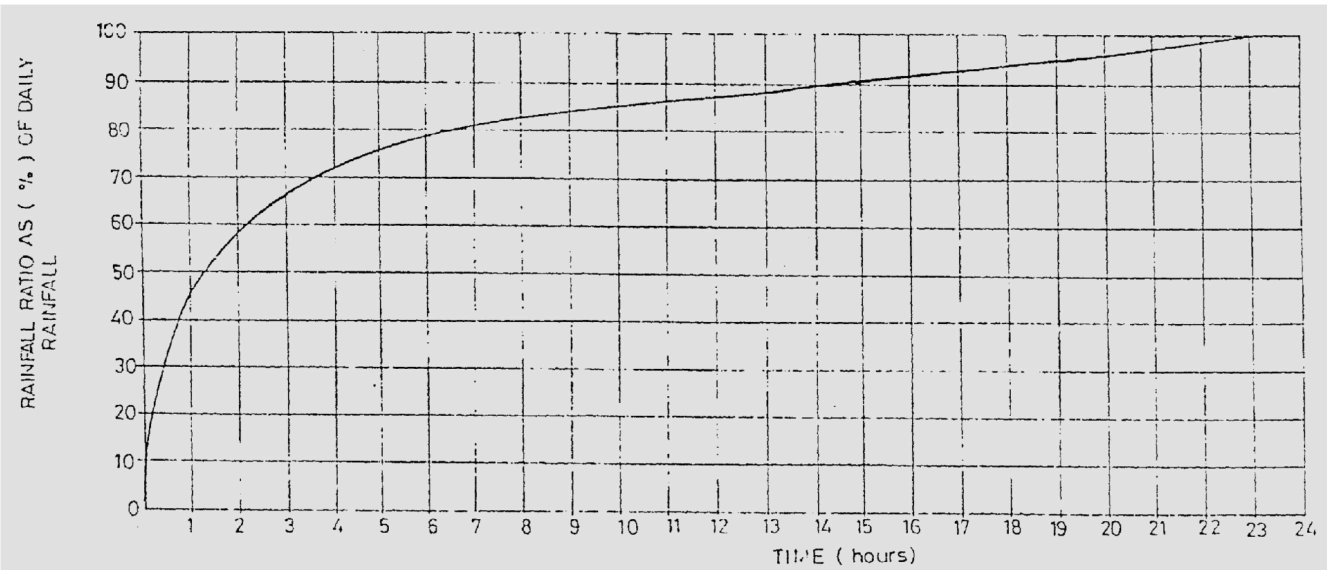


Figure 39 Time distribution of rainfall ratio as % of the daily rainfall, after U.S soil conservation service 1964

Table 29 Areal to point ratio (%), after U.S soil conservation service1964

Area km²	Duration l(hrs)	0.50	1.00	2.00	3.00	4.00	5.00	6.00	9.00	12.00	15.00	18.00	21.00	24.00
25		88	78	82	85	87	88	88	91	92	93	93	94	94
50		61	71	78	82	84	85	87	89	90	91	92	92	93
75		57	67	75	79	82	84	83	87	89	90	91	91	92
100		54	65	73	78	80	82	83	86	88	89	90	91	91
125		52	63	72	76	79	81	82	85	87	88	89	90	91
150		50	61	70	75	78	80	61	84	86	88	89	89	90
175		48	59	69	74	77	79	81	84	86	87	88	89	90
200		46	58	68	73	76	78	80	83	85	87	88	88	89
225		45	57	57	72	75	77	72	82	85	86	87	88	89
250		44	55	66	71	74	77	78	82	84	86	87	88	88
275		42	54	65	70	74	76	78	81	84	85	86	87	88
300		41	53	54	70	73	75	77	81	83	65	86	87	88
325		40	53	63	58	72	73	77	80	83	84	86	87	87
350		38	52	63	68	72	74	76	80	82	84	85	86	87
375		39	51	62	68	71	74	78	80	82	84	85	86	87
400		38	50	61	67	71	73	75	79	82	83	85	86	87
425		37	50	61	67	70	73	75	79	81	83	84	85	86
450		36	49	60	66	70	72	74	79	81	83	84	85	86
475		36	48	60	66	69	72	74	78	81	83	84	85	86
500		35	48	59	66	69	72	74	78	80	82	84	85	86
525		34	47	59	65	68	71	73	78	80	82	83	85	85
550		34	47	58	64	68	71	73	77	80	82	83	84	85
575		33	46	58	64	68	71	73	77	80	82	83	84	85
600		33	45	57	63	67	70	72	77	79	81	83	84	85
625		32	45	57	63	67	70	72	76	79	81	83	84	85
680		32	45	56	63	67	69	72	76	79	81	82	84	84
675		31	41	56	62	66	69	71	76	79	81	82	83	84
700		31	44	56	62	66	69	71	76	78	80	82	83	84
725		31	45	55	62	66	69	71	75	78	80	82	83	84
750		30	43	55	61	65	68	71	75	78	80	82	83	84
						49								

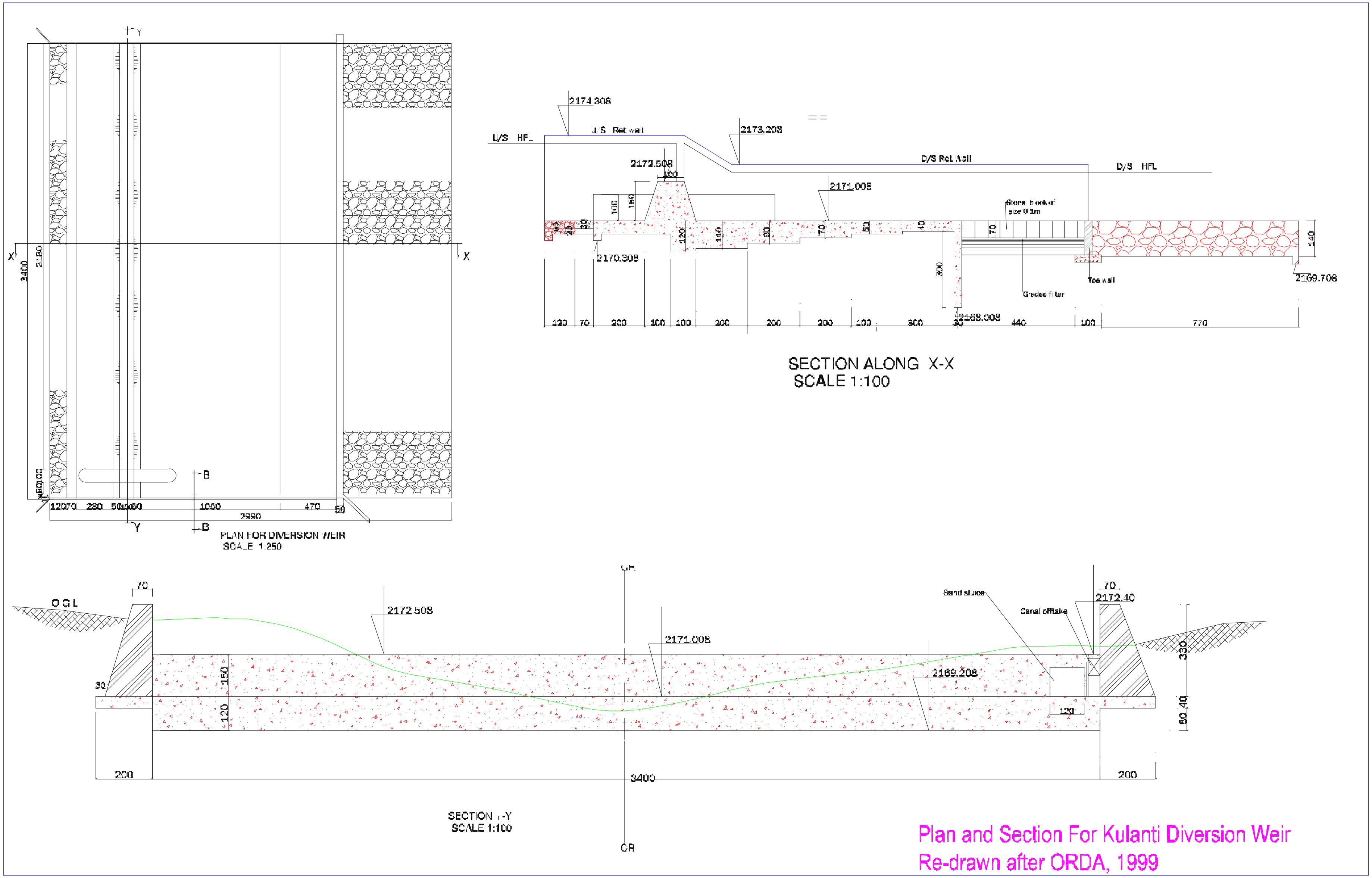
Table 30 Runoff curve number for hydrologic soil cover complexes (for catchment condition II and Ia = 0.2S, after U.S Soil Conservation Service 1964

Land use or cover	Treatment or practice	Hydrological condition	Hydrological soil group A	B	C	D
Fallow	Straight row	Poor	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	81	88
	Contoured	Good	65	75	82	86
	Contoured/terraced	Poor	66	74	80	82
	Contoured/terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured/terraced	Poor	61	72	79	82
	Contoured/terraced	Good	59	70	78	81
Close-seeded legumes or rotational meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured/terraced	Poor	63	73	80	83
	Contoured/terraced	Good	51	67	76	80
Pasture range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Woodlands (farm woodlots)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads			59	74	82	86
Roads, dirt			72	82	87	89
Roads, hard-surface			74	84	90	92

Table 31 Conversion table for Curve Numbers (CN) from Antecedent Moisture Condition Class II to AMC Class I or Class III (after Soil Conservation Service 1972)

CN AMC II	CN AMC I	CN AMC III	CN AMC II	CN AMC I	CN AMC III
100	100	100	58	38	76
98	94	99	56	36	75
96	89	99	54	34	73
94	85	98	52	32	71
92	81	97	50	31	70
90	78	96	48	29	68
88	75	95	46	27	66
86	72	94	44	25	64
84	68	93	42	24	62
82	66	92	40	22	60
80	63	91	38	21	58
78	60	90	36	19	56
76	58	89	34	18	54
74	55	88	32	16	52
72	53	86	30	15	50
70	51	85	25	12	43
68	48	84	20	9	37
66	46	82	15	6	30
64	44	81	10	4	22
62	42	79	5	2	13
60	40	78	0	0	0

Annex 9.2 Plan, section and Gate details for Kulanti Diversion weir



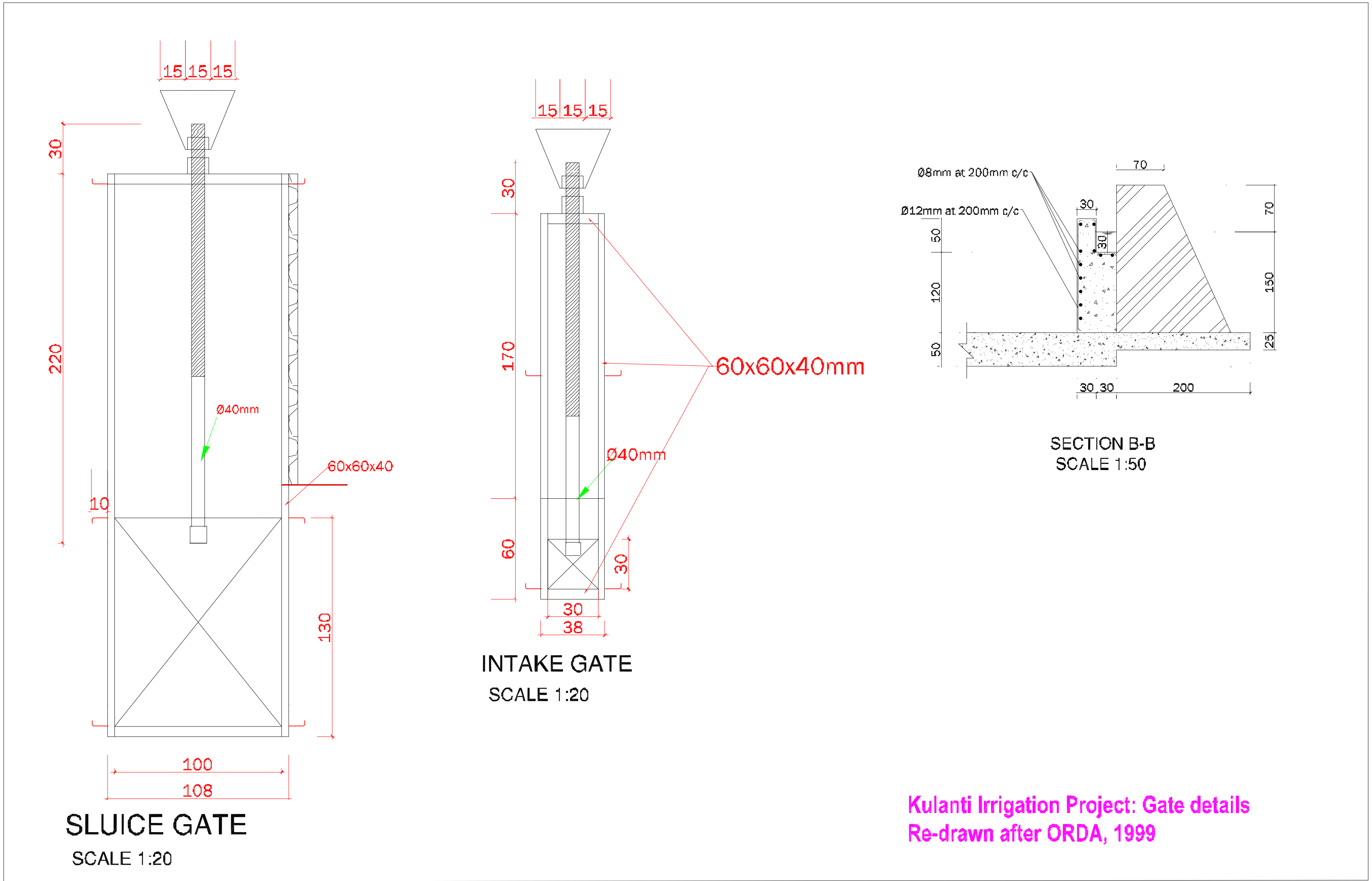


Figure 40 Plan, Section and Gate details for Kulanti diversion weir

Annex 11.1 Crop water requirement data and its results

Table 32 Effective rainfall determination for Kulanti IP

CropWat 4 Windows Ver 4.3

ETo and Rainfall Data

Data Source: C:\CROPWATW\CLIMATE\RROLD.CRM

Month	ETo (mm/d)	Total Rainfall (mm/month)	Effective Rain (mm/month)
January	4.10	3.0	0.0
February	4.70	24.0	7.0
March	5.10	35.0	12.5
April	5.40	33.0	11.5
May	4.50	85.0	44.5
June	3.60	227.0	143.9
July	2.60	345.0	226.5
August	2.60	347.0	227.9
September	3.60	237.0	150.9
October	3.80	91.0	48.7
November	3.70	63.0	29.1
December	3.60	12.0	1.0
Total (mm/Year)	1435.90	1502.0	903.5

N.B. Effective rainfall calculated using the following formulas:
Effective R. = 0.5 * Total R. - 5.0 ... (Total R. < 50.0 mm/month),
Effective R. = 0.7 * Total R. - 15.0 ... (Total R. > 50.0 mm/month),

Table 33 Crop data for the existing cropping pattern for Kulanti IP

CropWat 4 Windows Ver 4.3

Oat Crop Data

Data Source: C:\CROPWATW\CROPS\OAT5F.CRO

Growth Stages		Initial	Development	Mid	Late	Total
Stage Lengths	[Days]	20	30	40	30	120
Crop Coefficients	(Kc)	0.30	>>>	1.05	0.30	
Rooting Depths	[m]	0.30	>>>	1.20	1.20	
Depletion Levels	(P)	0.50	>>>	0.50	0.80	
Yield Factors	(Ky)	0.40	0.60	0.80	0.40	1.00

Onion Crop Data

Data Source: C:\CROPWATW\CROPS\O2F.CRO

Growth Stages		Initial	Development	Mid	Late	Total
Stage Lengths	[Days]	20	35	45	20	120
Crop Coefficients	(Kc)	0.70	>>>	1.05	0.95	
Rooting Depths	[m]	0.25	>>>	0.60	0.60	
Depletion Levels	(P)	0.30	>>>	0.45	0.50	
Yield Factors	(Ky)	0.80	0.40	1.20	1.00	1.00

Potato Crop Data

Data Source: C:\CROPWATW\CROPS\POTF.CRO

Growth Stages		Initial	Development	Mid	Late	Total
Stage Lengths	[Days]	25	30	45	30	130
Crop Coefficients	(Kc)	0.50	>>>	1.15	0.75	
Rooting Depths	[m]	0.30	>>>	0.60	0.60	
Depletion Levels	(P)	0.25	>>>	0.30	0.50	
Yield Factors	(Ky)	0.45	0.80	0.80	0.30	1.10

BARLEY Crop Data

Data Source: C:\CROPWATW\CROPS\B4F.CRO

Growth Stages		Initial	Development	Mid	Late	Total
Stage Lengths	[Days]	20	30	40	30	120
Crop Coefficients	(Kc)	0.30	>>>	1.15	0.25	
Rooting Depths	[m]	0.30	>>>	1.10	1.10	
Depletion Levels	(P)	0.60	>>>	0.60	0.90	
Yield Factors	(Ky)	0.20	0.60	0.50	0.40	1.00

Table 34 Soil data for Kulanti IP

CropWat 4 Windows Ver 4.3

Soil Data

Data Source: C:\CROPWATW\SOILS\SOILF.SOI

```
Soil description                  : Medium
Total available soil moisture    = 140.0 mm/m depth.
Initial soil moisture depletion = 0     %
Initial available soil moisture = 140.0 mm/m depth.
Maximum infiltration rate        = 40    mm/d.
Depth of root-restricting layer = 9.00 m.
```

Table 35 Crop water requirement for the existing cropping pattern for Kulanti IP

CropWat 4 Windows Ver 4.3

****

Crop Water Requirements Report

****

- Crop # : [All crops]
- Block # : [All blocks]
- Calculation time step = 10 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)	----------		
1/1	42.53	100.00	1.03	43.85	0.00	0.00	43.85	1.13
11/1	45.01	100.00	1.05	47.26	0.00	0.00	47.26	1.22
21/1	47.18	100.00	1.06	50.21	1.19	0.94	49.27	[1.27]
31/1	48.92	100.00	1.03	50.35	12.17	7.00	43.34	1.11
10/2	50.19	100.00	0.93	46.87	16.59	9.66	37.21	0.96
20/2	50.96	98.10	0.81	41.39	14.18	9.60	31.78	0.82
2/3	51.23	74.80	0.64	32.80	7.29	6.57	26.23	0.67
12/3	51.02	19.00	0.19	9.86	0.91	0.91	8.95	0.23
22/3	50.36	19.00	0.18	8.36	0.36	0.36	8.01	0.23
1/4	49.32	0.00	0.00	0.00	0.00	0.00	0.00	
11/4	47.95	0.00	0.00	0.00	0.00	0.00	0.00	
21/4	46.32	0.00	0.00	0.00	0.00	0.00	0.00	
1/5	44.51	0.00	0.00	0.00	0.00	0.00	0.00	
11/5	42.58	0.00	0.00	0.00	0.00	0.00	0.00	
21/5	40.62	0.00	0.00	0.00	0.00	0.00	0.00	
31/5	38.69	0.00	0.00	0.00	0.00	0.00	0.00	
10/6	36.85	0.00	0.00	0.00	0.00	0.00	0.00	
20/6	35.16	0.00	0.00	0.00	0.00	0.00	0.00	
30/6	33.68	0.00	0.00	0.00	0.00	0.00	0.00	
10/7	32.44	0.00	0.00	0.00	0.00	0.00	0.00	
20/7	31.48	0.00	0.00	0.00	0.00	0.00	0.00	
30/7	30.80	0.00	0.00	0.00	0.00	0.00	0.00	
9/8	30.43	0.00	0.00	0.00	0.00	0.00	0.00	
19/8	30.35	0.00	0.00	0.00	0.00	0.00	0.00	
29/8	30.55	0.00	0.00	0.00	0.00	0.00	0.00	
8/9	31.02	0.00	0.00	0.00	0.00	0.00	0.00	
18/9	31.72	0.00	0.00	0.00	0.00	0.00	0.00	
28/9	32.61	0.00	0.00	0.00	0.00	0.00	0.00	
8/10	33.64	0.00	0.00	0.00	0.00	0.00	0.00	
18/10	34.76	0.00	0.00	0.00	0.00	0.00	0.00	
28/10	35.92	81.00	0.37	7.96	9.23	9.23	0.00	0.00
7/11	37.06	81.00	0.37	13.60	10.95	10.95	2.65	0.07
17/11	38.13	81.00	0.38	14.46	7.41	7.41	7.05	0.18
27/11	39.08	92.40	0.58	22.75	6.13	5.46	17.29	0.44
7/12	39.87	100.00	0.80	31.95	0.00	0.00	31.95	0.82
17/12	40.46	100.00	0.96	38.82	0.00	0.00	38.82	1.00
27/12	20.39	100.00	1.02	20.73	0.00	0.00	20.73	1.07
Total	1453.76			481.21	86.41	68.10	414.39	[0.71]

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

STATEMENT

I herewith state that I prepared my Master of Science Thesis independently and that I did not use any other than the stated sources and aids.

Karlsruhe, 21 August 2008 **, Ewnetu Gedif Zerihun**

Place and date Signature

Full Name