Omo Valley Farm Co-operation P.L.C

Addis Ababa

# Feasibility Study and Detail Design of Omo Valley Farm Irrigation Project

## Section- I: Design Reports

## Volume-II: Irrigation and Drainage System

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# Feasibility Study and Detail Design of Omo Valley Farm Irrigation Project

## Irrigation and Drainage System

## Final Detail Design Report

**May, 2015**

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## List of Acronyms/Abbreviations

| Symbol | Description |
|---|---|
| CCA | Cultivable Command Area |
| ETo | reference crop evapotranspiration or crop water requirement |
| ETc | crop evapotranspiration or crop water requirement |
| FSL | design or full supply levels |
| g | gravitational acceleration |
| GCA | Gross Command Area |
| h | Head or pressure per unit weight |
| $h_L$ | head loss between two sections |
| Kc | crop coefficient |
| L | furrow length, length |
| n | Manning Roughness coefficient, |
| NIA | Net Irrigable Area |
| Q | discharge |
| $q_{peak}$ | peak discharge |
| $q_{rotations}$ | Rotational flow or discharge |
| R | hydraulic radius of a section |
| $t_c$ | time of concentration |
| Q | discharge |
| V | velocity |
| ρ | density of the fluid |
| $\tau_{max}$ | Boundary channel bottom shear stress, |
| m.a.s.l | Meter above sea level. meter above sea level |

# 1. Introduction

## 1.1 General Background

Ethiopia is endowed with abundant water resources potential and large areas of suitable lands and favorable climate for agricultural production. However, despite all this facts the country could not utilize these resources and maximize the benefit that should be gained from the sector. Understanding this fact the government of Ethiopia has given a major priority to this sector and identified the private investment sector as the one of the core players that is capable of transforming the countries agro industry potential in to reality. Omo Valley Farm Irrigation Project one of such projects, which is planned for establish a cotton plantation farm on the left bank of Omo River (gross irrigable area of 5,600 ha) and supplying to the planned textile factories.

## 1.2 Objective and Scope of the Study

The main purpose of the project is to produce cotton in the lower Omo plain through the development of irrigated agriculture on a 5,600 ha Gross Command Area.

The objective of the irrigation and drainage study are to design an efficient and suitable irrigation system which ensures reliable delivery of irrigation water at the right time and to the required amount as well as to design an efficient drainage system that ensures removal of excess moisture on and within the surface of the field. And as the component of the study and design, the following are to be undertaken:

- Review and collect the necessary data on the existing irrigation practice made concerning the proposed irrigation project.
- Based on the soil and land suitability study, demarcation of the irrigable area shall be done for the proposed cotton crop.
- Determine irrigation water requirement and decide the irrigation scheduling for proper rotation.
- Carry out detail design of the most effective and reliable irrigation and drainage system for the proposed project.
- Carry out hydraulic design and cost estimate for the irrigation and drainage structures.
- Prepare Bill of Quantities for the execution of the project

The report is part of the feasibility and detail design studies of omo valley farm irrigation project and it describes detailed design procedures, principles, and design criteria for irrigation and drainage system including structures.

The report structure has been summarized to have brief introduction in the first chapter. Chapter 2 provides the general description of the project, i.e. location, and topography. Chapter 3 defines irrigation and drainage system, while the Crop Water requirements are discussed in Chapter 4. This chapter also includes canal efficiency and irrigation unit size. The adapted surface irrigation methods are discussed on chapter 5 and the results of geotechnical investigation are provided on chapter 6. Chapter 7 and 8 describe the design of conveyance and drainage systems, respectively. Chapter 9 and 10 describe the design of canal and drainage structures, respectively. The Bill of Quantities of the irrigation and drainage system are presented on chapter 11.References are included as part of the report and Annexes are given to present the detail command areas and hydraulic parameters used in the design.

# 2. Description of Project Area

## 2.1 Project Location

The omo valley farm irrigation project is located in South Omo Zone of Southern Nations, Nationalities and Peoples Regional State (SNNPRS), in Hamer Woreda, Karo Kebele of South Omo zone. The Project area is located in the plain areas of Lower Omo-Gibe River Basin and falls in Hamer Woreda, Karo Kebele of South Omo zone.

The project area is part of Omo-Gibe River Basin and all of the proposed command area lies on the left side of the Omo River. Geographically, the entire project area is located $05^{O}$ 10'N to $05^{O}$ 16'N latitude and $36^{O}$ 12'E to $36^{O}$ 17'E Longitude i.e., between UTM189561m – 198452m N and 572087m – 575368m E.

The project site can be reached by the 750 km road from Addis Ababa, which is only asphalt road up to KeyeAfer Village and the rest 130km is a paved dry-weather road and the site is about 60km from Turmi village.

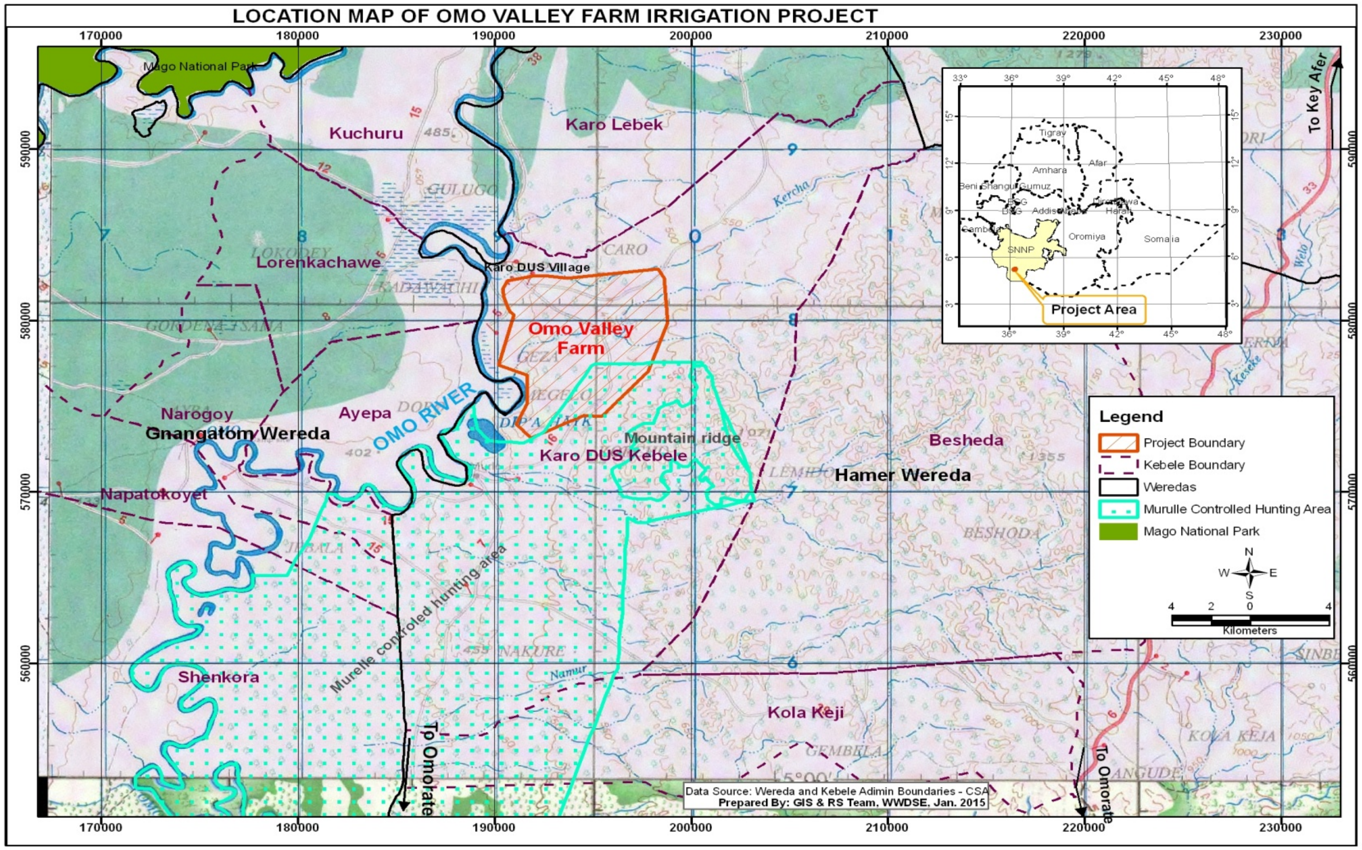


Figure 1. Location map of Omo Valley Farm Irrigation Project

## 1.1 Topography

The topography at the command area of omo valley farm irrigation project is considered as plain with an average altitude of about 420m a.s.l. The elevation ranges from 490m a.s.l. at the head of branch main canal (MC01) supplied by the booster pump to 390m a.s.l. at tail end of the irrigation command area. The slope of command area is considered as flat with a slope of less than 3 per cent in most places.

# 2 Definitions

## 2.1 Irrigation System

The irrigation system comprises a network of irrigation canals (main, secondary, tertiary and field canals) of different sizes and capacities to deliver the required amount of irrigation water from the source to the field.

Main Canal: It is the principal canal of the entire irrigation system that receives irrigation water from the pumping stations on Omo river and supplied to the secondary canals.

It is contour canal running at slope of ranging between1/4500 to 1/5000 and structure losses would be provided at cross regulating and gully/river crossings.

Secondary Canal: These are irrigation canals that off take directly from the main canal and deliver water to their individual command areas blocks. There are as many secondary canals as topographic situation dictates. Secondary canals are aligned across the contour on natural ground slope less than also slope of command area.

Tertiary Canal: These are irrigation canals that deliver water to tertiary blocks. Most of the tertiary canals are off taking from secondary canal except when there is less area to be irrigated near the main canal not requiring secondary canal in this case they are off taking from primary canal directly.

Quaternary Canal: Quaternary canals will off take from the Tertiary canals and are primarily responsible for delivering water to afield. The length of Field canals can vary from 500 to 1100m, but an optimum field length of 750m is proposed.

Irrigation Stream : The optimum farm stream (main d'eau) is a flow that can be handled efficiently by a farmer and is 40-250 l/s, which is the flow provided to each field during a certain interval and rotational basis. A stream flow ranging from is 40-250 l/s taken as optimum and this will dictate the size of area under each tertiary unit. The rotational turn days is decided up on the input from agronomy study.

## 2.2 Drainage System

A surface drainage system is comprises a network of drainage canals (main, secondary, and tertiary and field drains) of different sizes and capacities to collect and remove excess irrigation water and surface runoff.

Natural Drain: The existing natural drain can be used as a main drain whenever their use is applicable.

Interceptor Drain: This intercepts sheet flow and minor gully flow from area above command area to safe the primary canal, main access road and command area and conveys the flood or external flows to a natural drainage line. These will generally have cross drainage structures to discharge collected flows under the canals to natural gullies. For a canal excavated on a sidelong (sloping) ground, a catch-water drain, having designed carrying capacity to carry expected flood discharge from its catchment and leading it to a natural stream shall be provided. This will be further discussed in drain design.

Collector Drains: Collector drains mainly follows the natural drainage channels and depressions. These drains Convey surface water from several tertiary drains to river or natural streams, which ultimately outfall in to a natural rivers. These may also receive runoff coming out outside the command area that passes in Cross drainage structure.

Main Drain: The Main drain is the principal drain that outfalls into existing natural water course so that the excess water can completely be evacuated from the field. The Main drain receives excess water from secondary drains and in some instance from tertiary drains. Much effort will be exercised during the horizontal alignment of the system network to use the existing natural drain for the main drain

Secondary Drain: Secondary drains discharge into main drains which evacuate all water out of the area. In practice one will many times find secondary drains (and main drains) to be existing rivers or natural watercourses. Such drains should naturally be located in the lower parts of the area

Tertiary Drain: Tertiary drains collect water from lower order drains in the tertiary block (field drains) and convey this water to a secondary drain. Disposal can be into a natural gully or secondary drain or into waste land or a natural depression on the border of the command area.

Quaternary Drain: Quaternary drains run parallel to field canals and collect water from the field, field canal or directly from in-field furrows. Disposal can be into tertiary drains and sometimes in to higher order drain or into a natural/ artificial depression on the border of the command area.

## 2.3 Irrigation Units

Field Unit: The field is the smallest unit considered in the design of the project. It is the area that is irrigated using quaternary canals at maximum crop demand. The plot will have size of 60 ha when the field canal irrigate two way.

Tertiary Unit: Tertiary Units are Units are groups of fields, with an area around 30 to 190 ha (NIA). All fields within a unit will be irrigated during one rotation cycle.

Where there is less than optimum number of fields in a unit, the irrigation cycle will be truncated and the irrigation stream might be diverted elsewhere in the block.

Block: The area irrigated by a tertiary canal off-taking from a secondary canal. Blocks are variable in size being built up from groups of Tertiary units.

Command Area: The area irrigated by a main canal off-taking from the Main Canal. Individual command areas consist of a number of blocks which vary in size as they are dictated by topography.

## 2.4 Canal / Drain Numbering System

Main Canal : The project will have one main canal, Denotes as MC and a branch main canal, Denotes as MC01.

The cross-regulators on the main canal have been numbered, CR1, CR2, etc. and cross-regulators on the branch main canal have been numbered, CR01-1, CR01-2 with CR1 being the furthest cross regulator on the main canal upstream.

Escape structures on main canal have been denoted by ES1 being the furthest upstream on the secondary canal upstream.

Secondary Canal : Secondary canals are named in the order of their off taking chainage from the main canals, for example the first secondary canal in the main canal command is named SC-1 and the first secondary canal in the branch main canal (MC01) command is named SC-01-1.

In the rare occasions where secondary canals bifurcate they would be given suffixes as used for the secondary canal, for example SC-01-1 or SC-01-1 (0) would be the bifurcations on Secondary canal SC-01-1.

Tertiary Canal : Tertiary canals are labelled sequentially in the order they off-take from the left or right side of the secondary canal, using the two-letter abbreviation.

Canals off-taking on the left side use odd numbers and canals off-taking on the right side use even numbers. For example, the first tertiary off-taking on the left side of the first Secondary Canal on the main canal will be named TC-1-1 while the first tertiary off-taking on the left side of the first Secondary Canal on the branch main canal will be named TC-01-1-1

In the rare occasions where tertiary canals bifurcate they would be given suffixes as used for the secondary canal, for example TC-1-1 orTC-1-1(0) would be the bifurcations on tertiary canal TC-1-1.

Quaternary Canal : A similar numbering system is adopted for the quaternary canals. They are also labelled sequentially in the order they off-take with odd numbers used on the left side and even numbers used on the right side. Examples would be QC-1-1-1, which is the second off-take on the left side of tertiary canal TC-1-1.

A similar numbering system is adopted for all drain canals as adopted for irrigation

Drain Canals : A similar numbering system is adopted for all drain canals as adopted for irrigation canals. Drains will be numbered starting from the outfall and working upstream. The drainage channel categories will be identified using the following codes:

Main Drain: MD;

Interceptor Drain: ID

Collector Drain: CD

Secondary Drain: SD;

Tertiary Drain: TD and Quaternary Drain: QD.

# 3 Crop water requirement

## 3.1 General

Estimation of crop water requirement (CWR), which is directly related to irrigation system design and determination of the extent/size of field units, are essential for planning irrigation water and thereby increasing the yield of the irrigated crop.

## 3.2 Climate Data and Reference ETo

Reference crop evapotranspiration (ET0) has been estimated using the CROPWAT 8.0 computer program by Penman Montieth Approach (FAO I & D Paper No.56). And as there is no metrological stations located inside the project command boundary the Climatic data are transferred from nearby stations. (For detail information refer hydrological study of the project)

The summary of Climatic data and the resulting ETo values are provided in Table 3.1 below. The maximum ETo value occur in the month of February (6.6 mm/day), while the minimum ETo values occur in the months of May and June (5.4 mm/day).

**Table 3-1Climate and ETo Data**

Country: Ethiopia Station: Omo Valley Farm
Altitude: 420 m a.s.l.
Latitude: $5.22^0$ North Longitude: $36.25^0$ East

| Month | Min. Temp. | Max. Temp. | Humidity | Wind Speed | Sun Shine | Solar Rad. | ETo |
|---|---|---|---|---|---|---|---|
| | *(°C)* | *(°C)* | *Kpa* | *(m/sec)* | *(Hours)* | *(MJ/m²/d)* | *(mm/d)* |
| January | 16.7 | 37.1 | 1.4 | 1.9 | 9.2 | 21.9 | 6.2 |
| February | 17.3 | 36.8 | 1.5 | 2.1 | 9.2 | 23.0 | 6.6 |
| March | 17.5 | 36.4 | 1.6 | 2.3 | 7.0 | 20.3 | 6.5 |
| April | 17.4 | 35.0 | 1.9 | 1.8 | 8.7 | 22.8 | 5.9 |
| May | 17.1 | 34.3 | 2.0 | 1.7 | 8.4 | 21.5 | 5.4 |
| June | 17.5 | 33.7 | 1.9 | 1.9 | 8.4 | 20.9 | 5.4 |
| July | 17.0 | 34.1 | 1.5 | 1.9 | 7.9 | 20.4 | 5.7 |
| August | 17.2 | 34.2 | 1.3 | 1.9 | 7.7 | 20.8 | 5.9 |
| September | 18.0 | 35.6 | 1.8 | 1.9 | 8.7 | 22.8 | 6.1 |
| October | 18.1 | 35.7 | 1.9 | 1.9 | 8.9 | 22.6 | 6.0 |
| November | 17.4 | 35.9 | 1.8 | 1.9 | 8.6 | 21.2 | 5.6 |
| December | 17.3 | 35.4 | 1.7 | 1.8 | 9.2 | 21.5 | 5.6 |
| **Average** | **17.4** | **35.4** | **1.7** | **1.9** | **8.5** | **21.6** | **5.9** |

## 3.3 Rainfall data

The Effective monthly rainfall corresponding to 80 % dependable rainfall at irrigation project area has been estimated using the CROPWAT (version 8) by the USDA Soil Conservation Service Method and the result is shown below.

**Table 3-2 Effective Rainfall at 80 % Dependability**

| Months | Jan. | Feb. | Mar. | Apr. | May | Jun. | July | Aug. | Sep. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80% Dependable Rain, mm | 11.2 | 12.4 | 27.9 | 57.9 | 35.6 | 18.2 | 6.4 | 6.6 | 10.1 | 27.5 | 27.4 | 12.9 | 254.1 |
| Effective Rain, mm | 11.0 | 12.2 | 26.7 | 52.5 | 33.6 | 17.7 | 6.3 | 6.5 | 10.0 | 26.3 | 26.2 | 12.6 | 241.6 |

## 3.4 Soil data

The soil parameters important for calculating the irrigation scheduling and for this study we have selected sandy loam Soil which is the dominant soil of the project area. But in the actual calculations of scheduling both heavy and medium textured soil types will be considered based on the results of both physical and chemical characteristics of the soils of the project area. The effective depth of these soils area is in range of deep to very deep (more than 2m).

The most important soil parameters that are required for calculating irrigation intervals are the available soil moisture and Infiltration rate and the soil parameters for the selected soil texture classes are presented on the following table

**Table 3-3 Summary of the soil parameters**

| Texture Class | Hydraulic Conductivity (m/day) | Infiltration rate(cm/hr) | BD (g/cm$^3$) | FC (%) | PWP (%) | ASM (mm/m) |
|---|---|---|---|---|---|---|
| Sandy Loam | 0.7 | 4 | 1.73 | 8.99 | 3.96 | 87 |
| | 0.2 | 12.3 | 1.75 | 7.30 | 3.09 | 74 |
| | | | 1.78 | 6.85 | 3.68 | 56 |
| **Average** | **0.45** | **8.0** | **1.75** | **7.71** | **3.58** | **72** |
| Clay | 0.06 | 0.70 | 1.74 | 25.35 | 15.44 | 172 |
| | | | 1.84 | 25.38 | 15.74 | 177 |
| | 0.4 | 1.7 | 1.47 | 27.07 | 16.11 | 161 |
| | | | 1.91 | 29.57 | 19.07 | 201 |
| | | | 1.75 | 30.08 | 19.22 | 190 |
| **Average** | **0.23** | **1.2** | **1.74** | **27.49** | **17.12** | **180** |

## 3.5 Crop data

Crop data is one the basic inputs for estimation of crop water requirements for the different crops. The most important crop data required are the crop coefficient (Kc), rooting depth and canopy cover values at different growth stages, as well as the length of growth stages.

The basic crop data values used for estimation the irrigation water requirements of selected crops (Cotton /STG & CANDIA, Maize , Haricot bean, Vegetables , soya bean, sesame, Fruit , Forage crops , Observation plot ) are briefed under the following table.

**Table 3-4 Crop Coefficient [Kc] Values of different crops**

| **Crop Type** | **Kc Value as per the crop Growth Stages** | | | | **Crop Period** |
|---|---|---|---|---|---|
| | Initial | Developmental | Mid | Late | days |
| Cotton /STG & CANDIA | 0.35 | 1.0 | 1.2 | 0.6 | 150 |
| Maize | 0.3 | 1.0 | 1.25 | 0.4 | 125 |
| Wheat | 0.3 | 0.8 | 1.19 | 0.4 | 130 |
| Soya bean | 0.4 | 1.0 | 1.15 | 0.35 | 85 |
| Mung bean | 0.4 | 1.0 | 1.15 | 0.35 | 110 |
| Haricot bean | 0.4 | 1.0 | 1.15 | 0.35 | 110 |
| Sesame | 0.4 | 0.9 | 1.18 | 0.73 | 95 |
| Vegetable | 0.7 | 1.0 | 1.07 | 1 | 95 |
| Forage | 0.85 | 1.0 | 0.97 | 0.87 | 365 |
| Fruit | 0.7 | 0.7 | 0.71 | 0.73 | 365 |
| Observation plot | 0.35 | 1.0 | 1.24 | 0.7 | 150 |

## 3.6 Cropping Patterns

The extent of area that could be irrigated by a well, other than the dependable yield, depends on the types of crops grown and the cropping calendar. Cropping patterns, including planting date/period and crop duration, are developed following an assessment of existing cropping, as well as from economic, soil and agro-climatic suitability and marketing opportunities. The cropping intensity is derived from the overall cropping pattern and is used in feasibility studies to describe the likely impact of a proposed irrigation scheme over the pre-existing situation. For this study we have used a cropping pattern and intensity prepared for each type of crop and planned from the agronomy study and the proposed cropping patterns are provided on the following table.

**Table 3-5 Cropping patterns for Omo Valley Farm Irrigation Project during Wet Season**

| No | Crop / Variety | Area (ha) | Area, (%) | Crop Period (days) | Growing period (day) | |
|---|---|---|---|---|---|---|
| | | | | | Planting | Harvestin g |
| 1 | Cotton /STG & CANDIA | 4650 | 93 | 150 | 05/05 | 01/10 |
| | **Fixed Cropping Area** | | | | | |
| 1 | Vegetables | 50 | 1 | 95 | 15/06 | 17/09 |
| 2 | Fruit | 50 | 1 | 365 | 26/06 | 25/06 |
| 3 | Forage | 50 | 1 | 365 | 26/06 | 25/06 |
| 4 | Observation plot | 200 | 4 | 150 | 10/06 | 06/11 |
| | **Total** | **5,000** | **100** | | | |

**Table 3-6 Cropping Patterns for Omo Valley Farm-Irrigation Project During Dry Season**

| No | Crop / Variety | Area (ha) | Area , (%) | Crop Period (days) | Growing period (day) | |
|---|---|---|---|---|---|---|
| | | | | | Planting | Harvesting |
| 1 | Cotton /STG & CANDIA | 2550 | 50 | 150 | 20/10 | 18/03 |
| 2 | Maize | 600 | 12 | 125 | 30/10 | 26/02 |
| 3 | Wheat | 500 | 10 | 130 | 30/10 | 05/03 |
| 4 | Soya bean | 250 | 5 | 85 | 30/10 | 22/01 |
| 5 | Mung bean | 250 | 5 | 110 | 05/11 | 22/02 |
| 6 | Haricot bean | 250 | 5 | 110 | 25/10 | 11/02 |
| 7 | Sesame | 250 | 5 | 95 | 01/11 | 03/02 |
| | **Fixed Cropping Area** | | | | | |
| 1 | Vegetable | 50 | 1 | 95 | 01/11 | 03/02 |
| 2 | Forage | 50 | 1 | 365 | 26/06 | 25/06 |
| 3 | Fruit | 50 | 1 | 365 | 26/06 | 25/06 |
| 4 | Observation plot | 200 | 4 | 150 | 20/10 | 18/03 |
| | **Total** | **5000** | **100** | | | |

## 3.7 Estimation of Crop and Net Irrigation Water Requirement

For estimation of crop and irrigation water requirement the weighted the crop coefficient, Kc, values that varies according to the water demand and age of cotton at each month of the year has been taken. And since using cropwat software to determine irrigation water requirements for long duration [more than a year] as well as continuously cultivated crops like cotton is not somehow preferable a simple customized excel program has been used for this study.

The calculated net irrigation requirements (NIR) and duty of each month are shown on the following table 3.7. The peak NIR (6.6 mm/day) and duty (0.78 l/s/ha) value occurs in the month of January.

**Table 3-7 Net Irrigation Requirements (NIR) of OVFIP**

| **Month** | **NIR** | | **Duty for 24hr Operation** | **Duty for 20hr Operation** |
|---|---|---|---|---|
| | *mm/day* | *mm/month* | *l/s/ha* | *l/s/ha* |
| January | 6.6 | 206.0 | 0.78 | 0.936 |
| February | 5.3 | 147.4 | 0.67 | 0.78 |
| March | 1.3 | 39.8 | 0.27 | 0.204 |
| April | 0.1 | 1.5 | 0.02 | 0.36 |
| May | 0.3 | 10.5 | 0.15 | 0.048 |
| June | 3.5 | 106.3 | 0.51 | 0.492 |
| July | 5.7 | 177.1 | 0.64 | 0.792 |
| August | 6.1 | 190.2 | 0.64 | 0.852 |
| September | 4.4 | 131.8 | 0.31 | 0.612 |
| October | 0.7 | 20.4 | 0.14 | 0.048 |
| November | 0.7 | 22.2 | 0.17 | 0.12 |
| December | 4.8 | 148.9 | 0.60 | 0.672 |
| **Maximum/Total** | **6.6** | **1202.1** | **0.79** | **0.94** |

## 3.8 Irrigation Efficiencies

### Conveyance Efficiency

Conveyance efficiency measures the losses in the conveyance system which comprises seepage losses, operational losses (for example due to rotation of supplies to tertiary units) and evaporation losses. Of these the most important are seepage losses.

The adopted conveyance efficiencies are given below. For pipeline conveyance 100% conveyance efficiency may be assumed.

**Table 3-8 Conveyance Efficiency**

| Canals Name | Lined Canal | Unlined Canal |
|---|---|---|
| | | Loams |
| Main Canal | 95% | 90% |
| Secondary Canals | 95% | 90% |
| Distribution System (Tertiary Canals) | 90% | 88% |
| **Overall Conveyance** | **86%** | **71%** |

**Application efficiency**

Application efficiency is concerned with water losses starting from water delivered to the field and available to the crop and includes percolation, evaporation, off targets usage, runoff and so on.

For this a furrow type surface application method is selected and a70% application is adopted. Considering the fact that the project is commercial farm that is more likely to have the equipment, expertise and is expected to work reduce losses a lightly higher efficiencies are adopted

**Overall Efficiencies**

Overall efficiency for canals are given by the product of conveyance and application efficiencies, taking into account the conveyance and application method(s) and farm management.

For this study an Overall efficiency of 50% is taken for unlined channel and Furrows type application method in commercial farm. The overall efficiencies of each canal category are presented on the following table 3.9.

**Table 3-9: Irrigation efficiencies (%) of Omo Valley Farm Irrigation project**

| Canals Name | Overall Efficiencies (%) |
|---|---|
| Main Canal | 50% |
| Secondary Canals | 55% |

| | |
|---|---|
| Tertiary Canals | 62% |
| Quaternary Canals | 70% |

### 3.9 Peak Duty of Canal System

Based on the calculated irrigation water requirement and the efficiencies of varies components as discussed in the above sections the peak duty in l/s/ha for 20 hour irrigation for each canal category has been calculated and given in Table 3.10.

**Table 3-10 Peak Design Duty of Canals**

| Canals | Peak duty in l/s/ha | |
|---|---|---|
| | 24hr operation | 20hr operation |
| Quaternary Canals | 1.11 | 1.34 |
| Tertiary Canals | 1.27 | 1.52 |
| Secondary Canals | 1.41 | 1.69 |
| Main Canal | 1.56 | 1.87 |

## 3.10 Irrigation Interval

The theoretical maximum irrigation interval is derived on the basis of the consumptive use, rooting depth and soil moisture holding capacity and represents the period required to deplete the soil moisture reserve. The Irrigation interval is dependent on the growth stages of the crop and soil type. The relationship between the crop and the soil is expressed in terms of soil moisture depletion level. Studies indicated that during vegetative and yield formation periods, the depletion level is about 0.65.

The calculated the maximum irrigation interval of cotton plant for both sandy loam and clay textured soils is given in the following table 3.11. And the maximum irrigation interval is 24days for the cotton plant on clay soil and the minimum is 10 days for the cotton plant on sandy loam soil.

Therefore, 10 day irrigation interval would be adopted for the overall project and a target application depth of Zreq = 67mm, which equals the soil moisture extracted by the crop would considered for sizing of irrigation unit.

**Table 3-11 Theoretical Maximum Irrigation Intervals**

| Soil Texture Class | Peak Demand Period | Peak NIR (mm/day) | Root depths(m) | AWC (mm/m) | Allowable Depletion (%) | Maximum Irrigation Intervals (days) |
|---|---|---|---|---|---|---|
| Sandy Loam | January | 6.6 | 1.2 | 87 | 65 | 10 |
| Clay | January | 6.6 | 1.2 | 200 | 65 | 24 |

## 3.11 Sizing of Irrigation Unit

The sizing of the field unit is based on the stream size which is fixed based on crop water requirements. The field channel must be sized to meet the peak requirement for the crop for highest demand period.

***Irrigation Stream*** – is the maximum amount of flow rate that can conveniently be handled by one farmer or irrigator is a subject of some speculation, but for most situations of small-farmer, manual control it is in the range 25 to 50 l/sec but for commercial farms this can be increased by significant margin and 40 to 250l/sec is adopted for this project.

***Field unit: -*** is the smallest unit considered in the design of the project; generally it is 3-18ha. It is the area that is irrigated using furrows every 10days, at maximum crop demand, by a quaternary canal in one 20 hr day with the irrigation stream size of 40-251 l/sec.

***Irrigation Units*** are groups of fields units, no more than 10 fields of approximately 6 ha unit (or 60 ha). These would be irrigated by Quaternary canals.

***Tertiary Units*** are groups of Irrigation units, with an area of between30 and 180 ha (NIA). All fields within a unit will be irrigated during one rotation cycle.

It can be derived from the above scheduling that if a Tertiary unit has 120 ha (NIA) with 2 quaternary unit of each having 60ha (NIA), the quaternary canals would be designed for a flow rate of 161l/s irrigating 12ha/per day and completing the 120ha with in 10 day irrigation interval.

# 4 Surface Irrigation Methods

## 4.1 General

In order to select suitable irrigation conveyance and application methods, comparison were made among defend options and Open canals are proposed to convey water from the pumping station along the contour.

The main canal will have both unlined and lined sections, except over difficult ground and across streams and gullies. Down-slope conveyance leading from the main canal to the various canals will be by either lined canals with drops and or unlined canals with drops.

All secondary, Tertiary, and quaternary canals have been designed as unlined earthen canals with drops.

Surface (furrow) irrigation method has been selected as a method of the scheme. This selection is done based on considerations of among others, the crops, labor skill, soils, economics, and available technology.

## 4.2 Furrow Irrigation

Given the wide range of slopes and the high degree of mechanization expected furrow irrigation with siphon is the preferred method for efficient distribution of water to the fields.

In designing the field layouts, furrows will run along the minor gradient as the soils of the command area were found to be problematic in that the infiltration rate of the soils is very low.

Furrow evaluation test results show the furrows will perform well when they are level with a bund at the end so that sufficient amount of water is supplied to the furrow so that it gets longer period to infiltrate in to the soil.

A 100 mm head loss to deliver water to the furrows using siphons and a stream size of 2.5 to 5 l/s was assumed in the design which should be decided based on actual site conditions. This arrangement may be modified to suit different field gradients, discharge and other operational parameters.

## 4.3 Shape and Spacing of Furrow

Shape and spacing of the furrow depends on the water movement in the soil, crops and cultivation practices. Spacing between furrows is 0.9 m which is suitable to the cotton production.

The soils of the project area have a high to medium infiltration rates. And For this soil types within the command areas the recommended furrow depth and width is 150 mm and 300 mm, respectively which should safely store the required amount of water supplied to be infiltrated [FAO, 1994].

## 4.4 Furrow Length

The optimum length of the furrow is set to ensure even distribution of water down the length of the field. If the furrow is too long insufficient water will reach the bottom of the field, if it is too short then excess water will escape from the end of the furrow.

The optimum length is dependent on interaction of soil type, slope and irrigation application, as indicated in the following table which might be useful for future selections.

As per the client request, an optimum furrow length of 400 m was selected after evaluating a number of trial furrow lengths for various furrow operational and efficiency parameters.

The furrow length used in the sizing of the quaternary unit is 400 m minimum which will vary as per site conditions but in no case will be less than 300 m due to anticipated operational and application problems.

# 5 Geotechnical Investigations

## 5.1 General

Geotechnical investigations were carried out along the main canal (MC) alignment up to the first 13.14Kms and branch main canal (MC-01) alignment up to the first 4.85 Kms. The investigations include excavating test pits, infiltration tests in the test pits and taking representative samples for laboratory test. Details of the site investigations undertaken for the detailed design are summarized below.

- 15 test pits along the Main Canal, with a depth ranging from 3.0m to 5.0m. Four double ring infiltration tests were carried out in each test pit, one at 1m, one at mid-level and two at the bottom.
- To perform laboratory tests about 14 representative disturbed samples were collected. The following laboratory tests were carried out on selected samples
    - Atterberg limits
    - Particle size analysis
    - Natural moisture content
    - Specific gravity
    - Unit weight
    - Swelling tests
    - Consolidation testing, (Oedometer)
    - Direct Shear
    - Double hydrometer
    - Proctor compaction tests
    - Permeability
    - Sulphate and Chloride

## 5.2 Geotechnical Properties of Soils

The result the classification tests indicates that the soils along the Main Canal are four soil layers that; well graded sands (SW) , sandy clay ( SC), sandy silts(SM) and poorly graded sands (SP) in the Unified Soil Classification System.

Direct shear tests was undertaken on remolded samples that were collected from different depths and chainage along the main canal. The internal angle ($Ø^0$) ranged from $23^0$ to $30^0$and the cohesion (C) ranged from 9.9 to 54kpa .These values are presented on the following table.

**Table 5-1 Summary of Geotechnical Properties of Soils**

| Cross Drainage Structure Name | Canal Name | Chanage (m) | Easting | Northing | Depth (m) | Over Burden $Y_{Bulk}$, KN/m³ | C, KPa | Ø⁰ (digree) | $q_a$,KPa, Vesic | $q_a$,KPa, Terzagi | $q_a$, KPa, DCP-SPT Correlation Meyerhof's | $q_a$,KPa, Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Width, B = 0.5m | | | | | | | | | | | | |
| CD01 | MC | 1218 | 191199.9 | 573449.0 | 0.5 | 12.8 | 9.93 | 30.42 | 257.2 | 181.7 | 872.5 | **437.1** |
| | | | | | 1.0 | 12.8 | 9.93 | 30.42 | 285.0 | 193.5 | 1089.0 | **522.5** |
| | | | | | 1.5 | 12.8 | 9.93 | 30.42 | 316.5 | 205.3 | 1305.4 | **609.1** |
| | | | | | 2.0 | 12.8 | 9.93 | 30.42 | 343.8 | 217.1 | 1521.9 | **694.3** |
| CD02 | MC | 4814 | 194603.7 | 574258.6 | 0.5 | 13.23 | 18.93 | 28.26 | 278.7 | 386.6 | | **332.6** |
| | | | | | 1.0 | 13.23 | 18.93 | 28.26 | 289.2 | 415.9 | | **352.5** |
| | | | | | 1.5 | 13.23 | 18.93 | 28.26 | 299.7 | 450.2 | | **374.9** |
| | | | | | 2.0 | 13.23 | 18.93 | 28.26 | 310.1 | 477.7 | | **393.9** |
| CD04 | MC01 | 3432 | 198543.4 | 581616.3 | 0.5 | 13.5 | 54.39 | 23.57 | 721.7 | 542.3 | 936.32 | **733.4** |
| | | | | | 1.0 | 13.5 | 54.39 | 23.57 | 754.6 | 549.0 | 1168.64 | **824.1** |
| | | | | | 1.5 | 13.5 | 54.39 | 23.57 | 795.4 | 555.8 | 1400.96 | **917.4** |
| | | | | | 2.0 | 13.5 | 54.39 | 23.57 | 823.1 | 562.5 | 1633.28 | **1006.3** |

## 5.3 Permeability

The results of the infiltration tests indicate that the first 3.9km of the main canal, which is dominated by the sandy textured soils (mixture of both well and poorly graded) with high permeability range and this section of the main canal should be to be lined to protect excess seepage from canals. The permeability rate of the main canal reach beyond 3.9km are considered to be very small.

The summary of the permeability test results are presented on the following table 5.2.

### Table 5-2 Indirect method estimation of permeability by grain size and laboratory result of the Main canal (MC)

| **Name** | **Main Canal** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Chainage (m)** | **566.99 - 1892.79** | | **1892.79 - 3933.99** | | **3933.99 - 4565.85** | **4565.85 - 5045.78** | **5045.78 - 6444.54** | | **6444.54 - 7414.25** | | **74414.25 - 10041.19** | **10041.19 - 11038.09** | **11038.09 - 11587.56** | | **11587.56 - 13140** |
| **Depth (m)** | 0.0-2.50 | 2.50-5.0 | 0.0-1.80 | 1.80-3.0 | 0.0-3.0 | 0.0-5.0 | 0.0-2.8 | 2.8-5.0 | 0.0-2.0 | 2.0-5.0 | 1.5 | 2.0 | 0.5 | 2.0 | 3.1 |
| **Soil type** | SW | SC | SP | SW | CH | SP | SM | SP | SC | SP | SM | SM | CL | SP | SM |
| | **Permeability** | | | | | | | | | | | | | | |
| **Range** | cm/sec | | cm/sec | | cm/sec | cm/sec | cm/sec | cm/sec | cm/sec | cm/sec | cm/sec | cm/sec | cm/sec | | cm/sec |
| **Maximum** | 1.5*10-3 | 9.61*10-6 | 2.29*10-2 | 1.5*10-3 | 1*10-8 | 2.9*10-2 | 9.61*10-6 | 2.6*10-3 | 9*10-6 | 2.6*10-2 | | | 4.24*10-5 | | |
| **Minimum** | 1.5*10-4 | 9.61*10-7 | 2.29*10-3 | 1.5*10-4 | 1*10-9 | 2.6*10-3 | 9.61*10-7 | 4.4*10-4 | 9*10-7 | 2.6*10-3 | | | 4.24*10-6 | | |
| **Average** | **1.5*10-5** | **9.61*10-8** | **2.29*10-4** | **1.5*10-5** | **1*10-10** | **1.6*10-2** | **9.61*10-8** | **1.5*10-3** | **9*10-8** | **2.6*10-4** | | | **4.24*10-7** | | |

# 6 Canal Conveyance System

## 6.1 Canal Alignment

The layout of canal system was carried out with consideration of the following general principles:-

An irrigation canal should be aligned in such a way that maximum area is irrigated with the least length of channel and the cost of cross-drainage works will be the minimum. A shorter length of the canal has less loss of head and smaller loss of water due to seepage and evaporation so that additional area can be brought under cultivation.

The alignment of the canal should be such that the length of idle canal i.e., the portion of the canal from which no irrigation is carried out, is kept to minimum.

The alignment should not be made in rocky and cracked strata unless and otherwise there is no alternative alignment.

The alignment should be such that the canal cross the natural stream where the stream is straight with minimum water way.

As far as possible curves should be avoided and/or should be as gentle as possible in the alignment to avoid and/or minimize disturbance of flow and a tendency to silt on the inside and to scour on the outside of the curves (Refer Table 6-1).

**Table 6-1 Limiting Radius of Curvature for Irrigation Canal**

| Type of Canal | Minimum Radius |
|---|---|
| Sub-critical velocity | |
| Unlined | 7 T - 10 T* |
| Lined | 3 T |

Note: * T = surface water width

Source: [USBR, 1967]

And if it is not possible to avoid sharp curves in an unlined channel, then lining should be provided in curves up to at least 4 times the depth of flow downstream of the end of the channel curve.

#### i. Main Canal (MC)

The Main Canal (MC) would off take from the pumping station to irrigate the command area on left bank of Omo River. It was aligned as a contour canal running at a considerably gentle slope of ranging from 1/5000 to 1/4500 and structure losses are provided at cross regulators and gully/river crossings.

The starting full supply level (FSL) of for Main Canal at the outlet of delivery pipes site would be 423.0m a.s.l. and it has total length of 13.2 km out of which 3.2 km is idle canal. And a 10.0 m wide surfaced farm access road and interceptor drain has provided along the main canal alignment. And a 10.0 m wide surfaced farm access road and interceptor drain has provided along the main canal alignment.

#### ii. Branch Main Canal (MC-01)

The branching Main Canal (MC-01) would be supplied by the booster pumping station to irrigate the command area above m.a.s.l, it was also aligned as a contour canal running at a considerably gentle slope of ranging from 1/5000 to 1/4500 and structure losses are provided at cross regulators and gully/river crossings.

During design two possible Main Canal (MC-01) alignment options has been identified and comparation has been done based on their pipe length, main canal length and by the geotechnical formation and the number of cross drainge canals reqired accordingly

**Pipe length:-** the pipe length will be reduced from 3.5km (option 1) to 805m (option2)

**Main Canal Length**: - the branch main canal length of option 2 will be increased by around 3.4km compared to option 1.

Geological Formation: the geological formation of the main canal alignment of option 2 characterizes by a poorly graded Sand unit (SP) that very dissected, and very permeable formation, which means the first 3.4km, requires a masonry lining. The construction of this canal will be difficult and require more construction time.

And according to the hydrological study data and preliminary analysis on global map the first 3.4km of the main canal will cross at list four major gullies and need extra four cross drainage structures.

Considering the above facts option 1 is selected for detail design and The starting full supply level (FSL) of for branching Main Canal (MC-01) at the outlet of delivery pipes site has been fixed art 490m a.s.l. and it has total length of 4.8km. And a 10.0 m wide surfaced farm access road and interceptor drain has provided along the branching Main Canal (MC-01) canal alignment

### iii. Secondary Canals

There are eight Secondary canals off taking directly from the main and branch canals and are planned to supply command area blocks that are bounded by two major natural drains or depressions.

The secondary canals generally aligned across the contour on natural ground slope in sub-critical channels with frequent drop structures with FSL around ground level so that they could be able to command every field in the unit. A 10.0 m wide surfaced farm access road would be provided along the secondary canal alignment.

As a consequence of balancing cut and fill the water level will be above ground level upstream of drop structures. In addition, the water level will be set to be at least 0.5m above ground level upstream of cross-regulators, so that off-taking tertiary canals can command their head reaches.

### iv. Tertiary Canals

The entire command area of the project is planned to be irrigated using the tertiary canals that off take directly from the secondary canal and supplies irrigation water to quaternary canals.

The tertiary canals are generally aligned along the contours in earth channels with sub-critical flow with the FSL at off taking structures set to be at least 0.35m above ground level so that head reaches of fields could be irrigated (without land leveling if possible). A 6.0 m wide surfaced farm access road and tertiary drain would be provided along the tertiary canal alignment.

### v. Quaternary Canals

A quaternary canal is the smallest canal which offtake from tertiary canals. These canals are planned to supply around 60ha of cotton plantation fields that are bounded by quaternary and a territory drains. The filed would have a maximum 400m furrow length and 750 m long quaternary canal with some expiation.

All of quaternaries are aligned down the major gradient and so will have frequent small check structures to control bed erosion and water level for easy delivery of water to adjacent furrows. A 4.0 m wide surfaced farm access road would be provided parallel to the quaternary canal alignment.

## 6.2 Determination Full Supply Level

During the planning process for the irrigation system canal layout involves the determination of design water levels (FSL) at various points of the canal system and preparation of the complete working head at the different reach of the entire canal system from main canal up to quaternary canals (especially at offtake point).

### i. Command statement

The command statements have been prepared for secondary, tertiary & quaternary canals and accordingly the requirement of FSL has been decided. The statement was prepared at the different reach of the entire canal system starting from the field up to main canal. The following points have been taken into consideration for preparing the command statement.

***Critical point***: - It is the spot, which requires highest water level due to the combined impact of spot level in terms of elevation and its distance from the irrigation channel /outlet. Thus the critical point has been identified.

***Head over the field:*** – It has been assumed that the depth of water should be a minimum of 0.25m over the critical spot level.

***Canal head losses***: - In order not to lose any command area all the canal head losses in the canal system should be identified and the minimum practical structure losses should be added on the calculated Critical Ground Level and the adopted minimum head over the field, which is 0.25m. The minimum canal and structure head loses used for this study are given in the following table 6.2**.**

**Table 6-2: Canal Head Losses**

| S/N | Description | Head Loss, M | Remark |
|---|---|---|---|
| 1 | Cross Regulators and Control Structures (Main Canal) | 0.2 to 0.4 | |
| 2 | Secondary Canal Head Regulators | 0.2 to 0.4 | |
| 3 | Tertiary Canal Head Regulators | 0.2 | |
| 4 | Quaternary Canal Head Regulators | 0.2 | |
| 5 | Secondary Canal Cross Regulators | 0.2 | |
| 6 | Tertiary Canal Cross Regulators | 0.2 | |
| 7 | Culverts (Pipe / Box) | 0.05 to 0.15 | |
| 8 | Inverted Siphons | 0.3 to 0.5 | Should be avoided |

**i. Working Head**

It is required to provide working head at the head of the offtaking channel, which is the difference in the FSL of the parent channel and that of the offtaking channel, in order to facilitate the flow of the design discharge. To overcome such problems, the following working head as given in Table 6.3 has been adopted:

**Table 6-3 Working Head for Different Canals**

| Sr No | Parent canal | Off-taking canal | Working head |
|---|---|---|---|
| 1. | Main Canal | Secondary Canal | 0.20 m |
| 2. | Secondary Canal | Tertiary Canal | 0.2 m |
| 3. | Tertiary Canal | Quaternary Canal | 0.2 m |

## 6.3 Hydraulic Design of Canal Section

### 6.3.1 General

This chapter covers the various design aspects of the canal conveyance system that are defined in section 3.1 of this report.

### 6.3.2 Design Criteria

The detailed criteria for the hydraulic design of canals have been revised and furnished as enclosure in the "Irrigation and Drainage System Planning and Design Criteria" report: The hydraulic design of irrigation channels has been done accordingly.

### 6.3.3 Design capacity

Canal systems should have adequate capacity to deliver the required water amount when it needs. Thus, they are designed on a capacity large enough to carry in the maximum period.

The net irrigable area, the maximum duty water requirement, flexibility for future needs and other mandatory releases other than irrigation are the basic required parameters to define the canal flow capacity.

The design of the system allows flexibility, if any change in the future happens such as need of irrigable area expansion and/or unforeseen events come during operation. Thus, a flexibility factor of 7% is considered for all the canals.

The canal capacity reduces from the head reach towards the tail according to the command area it covers. Therefore, the Design discharge of secondary and branch main canals that offtake directly from the main canals are summarized in table 6.4.

**Table 6-4 Design Discharge of Canals**

| Name of off taking canal | NIA | Design Discharge at the Head of SC |
|---|---|---|
| | Ha | $m^3$/sec |
| SC-1 | 472.3 | 0.82 |
| SC-2 | 140.5 | 0.25 |
| SC-3 | 100.2 | 0.17 |
| SC-4 | 1314.2 | 2.29 |

| | | |
|---|---|---|
| SC-5 | 712.7 | 1.24 |
| MC-01 | 2082.3 | 4.17 |
| Additional un surveyed area | 176.8 | 0.31 |
| **TOTAL** | **5000** | |

### 6.3.4 Cross- section design

All the canals have been considered as unlined earthen canals with a trapezoidal shape and are designed using Manning's formula as defined below:

$$Q = \frac{A \times R^{2/3} \times s^{1/2}}{n}$$

where: Q = discharge ($m^3/s$)
R = hydraulic radius
s = hydraulic gradient
n = Manning's roughness coefficient

### 6.3.5 Roughness Coefficients

The type material on the side and bed of the canal as well as the Channel alignment (sinuosity) has an influence on the value of roughness coefficient.

A Manning roughness coefficient, n, of 0.025 has been used for the design of canals.

### 6.3.6 Side slopes of the canal

The type of soil in which the canal is to be constructed and the depth of the canal govern the side slope of the canal cross-section. The side slopes of a canal depend upon the stability of the material in which it is constructed. Accordingly the side slopes that has been used for the design of canals are listed in the following table 6.5

**Table 6-5 Selected Side Slopes**

| Canal Name | Side Slope (1V: m H) |
|---|---|
| Quaternary canals | 1.0 |

| | |
|---|---|
| Tertiary canals | 1.0 |
| Secondary Canals | 1.5 |
| Main Canal | 1.5 |

### 6.3.7 Permissible Velocity and Bed Slope

All unlined canals have been designed to be non-erosive by controlling flow velocities and permissible slopes. The limiting velocities and slopes are determined using the “tractive force” method.

The unit tractive force, τ, is given by:

$$\tau = C \times W \times R \times s$$

where:

C = Coefficient depending on the shape of the channel and the part of the canal considered.

W = Specific weight of water (9 810 N/m$^3$).

R = Hydraulic radius (flow area / wetted perimeter).

s = Hydraulic gradient.

The unit tractive force is not uniformly distributed along the wetted perimeter and the value of C on the sides and bottom of a trapezoidal channel is different. However, the tractive force on the bed is greater than that on the sides; hence the bed value is used in comparison with the permissible tractive force.

The recommended C values are given in the following table 6.6.

**Table 6-6 C Values in Tractive Force Equation [WV, 1974]**

| Bed Width to Water Depth Ratio (b/d) | Value of C | |
|---|---|---|
| | On Sides | On Bed |
| 1 | 0.70 | 0.80 |
| 2 | 0.73 | 0.90 |
| 3 | 0.73 | 0.95 |
| 4 | 0.74 | 0.96 |
| 5 | 0.74 | 0.97 |
| 6 | 0.75 | 0.98 |

The permissible tractive force of 3.0 $N/m^2$ was taken for the design of canals. A trial and error process must be followed to establish the maximum allowable slope of canals for a particular discharge to ensure that the tractive force does not exceed the permissible limit. Accordingly the permissible velocity of 0.30m/s to 0.90m/s has been adapted.

### 6.3.8 Canal Bed Width Depth ratio (B/D)

For an unlined channel, a stable section (b/d value) depends on the discharge as well as the soil in which the channel is made and the sediment being transported. Basically the higher the discharge the larger the b/d value, while the more tenacious (cohesive) the soil the tighter the channel section (smaller b/d value).

For unlined canals in non-cohesive material the minimum stable b/d ratio can be determine by Lacey water surface width formula i.e. b/d=1 for canals with Q < $0.2m^3/s$, But $b/d = 1.76*Q^{0.35}$ for canals with Q > 0.2 $m^3/s$.

### 6.3.9 Free board

The USBR recommends two types of canal freeboard. Canal lining and canal banks should be extended above the normal full supply level as a safety measure to protect the conveyance system from overtopping.

A 0.5m minimum freeboard has been adapted for main canal. However, in the tail area of the main canal it might lower to 0.4 depending on the discharge. The free board values adapted for design of secondary canals are presented on the following table 6.7.

**Table 6-7 Freeboard for Unlined Secondary Canals**

| Discharge ($m^3/s$) | F: Freeboard to Embankment Top (m) |
|---|---|
| 0 - 0.5 | 0.30 |
| 0.5 - 1.0 | 0.40 |
| 1.0 - 2.0 | 0.50 |

For the tertiary and quaternary canals the freeboard has been set to be 0.2m and 0.15m, respectively.

### 6.3.10 Top Bank width

Embankment works are carried out according to the practical aspects of construction and possible future use by local vehicles. The width to be used for main, secondary, tertiary and quaternary canals is given in Table 6.8

**Table 6-8 Selected Minimum Bank Top Width**

| Category of Canal | Minimum Bank Top Widths | |
|---|---|---|
| | Inspection Bank | Non-inspection Bank |
| | *m* | *m* |
| Quaternary Canal | 0.5 | 0.5 |
| Tertiary Canal | 1.0 | 1.0 |
| Secondary Canal | 3.0 | 1.5 |
| Main Canal | 5 | 2.0 |

### 6.3.11 Saturation Gradient

Bank back slopes are chosen to maintain the seepage phreatic surface at least 0.3 m within the toe of the embankment for canals in fill. The seepage (hydraulic) gradient adopted generally varies from 1 in 3 (for heavy soils) to 1 in 7 (for light soils). To fulfill these criterion counter-berms (i.e. berms on the outer bank) may be cost effective.

## 6.4 Details of Canal Conveyance System

### i. Main canal (MC)

The Main Canal (MC) off taking from the pumping station and planned to supply 5,000ha (NIA) by both gravity and it is designed to carry the 10.0 $m^3/s$ on the basis of 20hr irrigation operation and 7% flexibility. And it has total length of 13.2km out of which 3.244 km is idle canal.

In order to avoid the excessive seepage losses and the construction difficulty due to the geological formations the main canal has been designed as a masonry lined rectangular section canal for the first 3.9km, but for the rest of the Main Canal reaches it has been designed as unlined earthen canals with a trapezoidal cross section and the design capacity of the canal has been calculated by the Manning's flow formula. The side slope has been set to 1:1.5 (V: H) and manning Roughness Coefficient, '*n*' = 0.025 has taken. The details of hydraulic parameters of the main canal are provided on annex 2.

Along the contour section of main canal a minimum embankment top width is set to 2.0m non inspection side and 5.0 for inspection side as well as a 10.0 m wide surfaced farm access road and interceptor drain has provided along the main canal alignment, approximately 25m away from the canal centerline.

Six head regulator structures have been provided on the main canal for regulating to secondary and branch main canals that are off taking directly from main canal. And another four cross regulator have been provided on the main canal to maintain the full supply of the main canal at upstream of the gate while passing the required discharge over the gate for the downstream users.

### ii. Secondary Canals

There are five Secondary canals off taking directly from the main canal and another two secondary canals would offtake from the branch main canal. The Secondary canals will flow 20 hr/day and distributed the flow to each off-taking tertiary canal in proportion to the area irrigated.

Secondary canals have designed as unlined earthen canals with a trapezoidal cross section. Side slope the canal has been set to 1:1.5 (V: H). The Minimum embankment top width is set to1.5m and a 10.0 m wide surfaced farm access road will be provided along the secondary canal alignment. The details of hydraulic parameters of the secondary canals are provided on annex 2.

### iii. Tertiary Canals

Tertiary canals will flow for 20 hr/day and flow will be distributed down each off-taking quaternary canal in proportion to the area irrigated.

The tertiary canals are generally aligned along the contours in earth channels with sub-critical flow with the FSL at off taking structures set to be at least 0.3m above ground level so that head reaches of fields could be irrigated (without land leveling if possible).

Tertiary canals have designed as unlined earthen canals with a trapezoidal cross section. Side slope the canal has been set to 1:1 (V: H) and a freeboard has been set to 0.2m. The Minimum embankment top width is set to 1.0m. Tertiary drain and 6.0 m wide surfaced farm access road will be provided along the tertiary canal alignment. The details of hydraulic parameters of the tertiary canals are provided on annex 2.

#### iv. Quaternary Canals

A quaternary canal is the smallest canal which branches off from tertiary and runs in the middle of the entire length of a field. In order to select cost effective quaternary canal, comparison was made among unlined earthen, masonry, concrete and flexible gated pipe (specifically flexi flume) per each linear meter and each block. And After reviewing the results and the client's interest, unlined earthen quaternary canals are adopted.

Quaternary canals will flow for 20 hr/day and will irrigate around 60ha of cotton plantation fields on rotational basis. Quaternary canals are designed unlined earthen canal as a trapezoidal cross section and will have minimum bed width of 0.25m and side slopes of 1.0:1.0 (V: H). The flow depth depends on the discharge and the bank top width is set to a minimum of 0.5m.

Irrigation Water will be siphoned out from quaternary canals to feed the furrows of a field. The Discharge through siphon depends on the diameters of the pipes and the difference between the water surfaces in the quaternary canal and in the furrow.

For omo valley farm irrigation project it is proposed to keep water level at the head of siphons at least 0.25m above ground level, which is capable of providing furrow discharge of 2.5 - 5lit/sec by siphon with4 - 7cm diameter.

Therefore, for the design quaternary canal discharge of 160lit/sec, 64 siphons will be used at a time which means when fields located at both sides of quaternary canal are irrigated 32 siphons will be used at each side.

## 6.5 Vertical Alignment or Longitudinal section design

The following principles should be taken in to consideration during the design of irrigation system:

- the water level in supply canals should be sufficiently high to irrigate the highest areas for which irrigation is envisaged;
- A balance between cut and fill is economic for construction of supply canal. Canals in high fill are more difficult to construct and would in general lose more water by seepage; this would certainly be so when also the bottom of the canal is above the original ground surface: *at least the bottom* of a canal.

After the canal cross-section has been designed, the longitudinal section is calculated which represents the vertical alignment of canals and the following procedures have been done...

a) The ground level profiles along the final alignment of the canal have been taken.

b) The canal Full Supply Level at the head of each canal has been fixed and longitudinal profile of each canal computed by using the canal cross section parameters. The head losses at canal regulators, siphons, etc has been determined from their designs and incorporated in on L-section design.

c) Checking whether or not the full supply level of the off-taking channel have the required working head, if not revise the up-stream water surface profile until it attains the working head requirement.

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# 7 Surface Drainage System

## 7.1 General

Drainage requirements for the project, where most of the command areas is considered as flat or almost-flat, it is apparent that the system is expected to comprise surface drains with free outfalls.

Drains will be required primarily to remove excess water during the rainy season, to discharge excess flows from irrigation canals and/ or to convey flows that might be created due to some operational mistakes. We also require the drainage system to control maximum groundwater levels and the risk of salinization.

Drains fall into two categories:

- ***Internal Drain**:* excavated within a command area to drain excess rainfall falling onto land and possibly control groundwater levels.
- ***External Drains:*** conveying runoff from floods arising from areas upstream of the command area, as well as runoff from within the command area. They are usually well defined water courses which usually require channeling, stabilization measures and/or bank protection. The external drains may be associated with soil and water conservation measures for sloping land.

This chapter is predominantly concerned with internal drains (drainage system from the farm) and interceptor drainage canals that are connected to cross drainage structures.

## 7.2 Drain Alignment and Design Water Levels

### Channel Layout

The alignments of drains depend on the alignment of irrigation canals and will be aligned to follow natural drainage lines, connecting low lying areas / fields. As for irrigation channels, curves should be as gentle as possible to avoid scour damage. A radius of 8 - 10WS is recommended where WS is the water surface width for the design discharge.

### Design Water Levels

Quaternary drains collect excess water from the fields and the FSL in the Quaternary drains will be fixed at least 0.15 below the ground level.

Tertiary Drains drain excess surface water directly from fields or from Quaternary drains and the design water level should be the minimum ground level for the fields being drained, or 0.2-

0.30 m below the average field level or at least about 0.05 - 0.10 m below the FSL of the Quaternary drains.

The design water level in Collector Drains is dependent on the water levels required by the Tertiary Drains where they join. Similarly the levels in the Main Drains are dependent on the design water levels in the Collector Drains where they join.

Normally the drop at drain junctions will be minimal, about 0.05 - 0.10 m. However, the design water level in the drainage channels should ideally always remain below natural ground level and drain drops will be allowed up to 1.0 m where required.

## 7.3 Drainage Duty

The design discharge is the product of the drainage duty and the drainage area. The drainage area is the gross or total land area upstream of the point considered.

For small Tertiary and Quaternary drains a constant section/design discharge is usually adopted. However for larger collector and main drains the design discharge increases along the drain.

Design storm depths for various return periods and estimate of the drainage modulus (l/s/ha) are given in the hydrology / water resource report the results of which is shown in the following tables.

**Table 7-1 Rainfall Data for a Given Duration and Return Period**

| Return Period | 24 Hours Rainfall Depths (mm) |
|---|---|
| 5 | 71.3 |
| 10 | 79.3 |
| 25 | 89.4 |
| 50 | 96.8 |

The rational formula have been used to calculate the drainage discharge

$$Q = \frac{CIA}{360}$$

where: Q = Peak discharge ($m^3/s$)
I = Rainfall intensity of desired duration (mm/hr)
A = catchment area (ha)
C = Runoff coefficient

The Recommended Runoff coefficient, C value for sandy loam soils with moderate vegetation and wet initial soil moisture condition is shown on the following table.

**Table 7-2 Recommended Runoff coefficient, C value for OVFIP**

| Catchment Cover | Command Slope (%) | Recommended C |
|---|---|---|
| Cotton field | 0-2 | 0.12 |

The five years return period design storm (71.3 mm) and the recommended C (0.12) values are used to arrive at the peak drainage duty values in the following table.

**Table 7-3 Drainage Duty (l/sec/ha)**

| Return Period | Duration of Flood, days | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 5 | 0.99 | 0.49 | 0.33 | 0.25 | 0.20 | 0.16 | 0.14 |

Hence, the Drainage duty of the project area is taken to be 0.99 l/s/ha which must be disposed in 24hours' time.

## 7.4 Cross Drainage Floods

The Main Canal will cross four of large drainage channels , which are the tributaries of the Omo River and it is proposed to provide a total of four cross drainage structures on this major tributaries and the small gullies will be diverted in to these rivers by an interceptor drains.

The design peaks floods for different return periods have been estimated using the SCS method by using a mean value for Tc value and design rainfall depths as described in the previous section (table 7.4). For hydraulic design of the cross-drainage structures is the 1 in 25 year return period peak has been adopted.

There are 4 cross drainage structures are provided on the main canal and one cross drainage structures has also been provided on the branch main canal. The peak flood discharge estimates are provided in the following table for detail information refer the Climatology and Hydrology Study Report.

**Table 7-4 Peak Flood Discharge of Cross Drainage Structures**

| Cross Drainage Points | Coordinates at Cross Drainage Structures | | Catchment Area, $km^2$ | Discharge $m^3/s$ | | | | |
|---|---|---|---|---|---|---|---|---|
| | Easting | Northing | | $Q_5$ | $Q_{10}$ | $Q_{25}$ | $Q_{50}$ | $Q_{100}$ |
| **CD01** | 191200.69 | 573449.03 | 7.20 | 1.9 | 2.8 | 4.1 | 9.4 | 12.6 |
| **CD02** | 194603.67 | 574258.64 | 10.45 | 2.1 | 3.2 | 5.0 | 11.8 | 14.9 |
| **CD03** | 196023.37 | 575536.15 | 20.96 | 5 | 7.8 | 12.9 | 22.2 | 29.2 |
| **CD04** | 194761.74 | 579455.30 | 9.91 | 1.8 | 2.8 | 4.4 | 11.1 | 13.9 |

## 7.5 Hydraulic Design

### 7.5.1 Design Criteria

The detailed criteria for the hydraulic design of drainage canals have been revised and furnished as enclosure in the “Irrigation and Drainage System Planning and Design Criteria” report: The hydraulic design of drainage channels has been done accordingly.

### 7.5.2 Cross section Design

A uniform flow formula such as Manning is used to determine the design capacity of drainage channels.

### 7.5.3 Channel Roughness

The channels are designed for a Manning’s n value assuming the channel is established with some weed growth and not freshly dug. A Manning’s n of 0.025 is likely to be suitable.

### 7.5.4 Longitudinal Slope, Maximum Permissible Velocities and Tractive force

The longitudinal slope and prism design should result in suitable flow velocities. Longitudinal slopes of a drainage channel normally decrease going downstream as design discharge increases.

The permissible tractive force of 3.0 $N/m^2$ was taken to design drainage canals and the permissible velocity ranging from 0.30m/s to 0.90m/s has been adapted.

### 7.5.5 Bed Width to Depth Ratio (B/D)

Choice of a suitable width B/ D ratio is important if the channel is to be stable. An over tight section could develop meanders, while an over-wide section will be conducive to high weed growth and take up more land. The B/ D ratios adapted for this study are presented on the following table 7.5.

**Table 7-5 Recommended B/D Ratios for Drain Canals**

| Discharge ($m^3/s$) | B/D (Drainage Channels) |
|---|---|
| < 1 | 2 |
| 1 - 3 | 3 |
| 3 - 20 | 4 |
| > 20 | > 5 |

### 7.5.6 Drain Side Slopes

Side slopes for a trapezoidal drain section depend on the type of material in which the drain is constructed. Recommended side slopes are given below.

**Table 7-6 Recommended Side Slopes for Drainage Channels**

| Type of Soil | Side Slope (1V : H) |
|---|---|
| Quaternary Drain | 0.5 |
| Tertiary Drain | 1.0 |
| Interceptor and Collector Drains | 1.5 |
| Main Drain | 1.5 |

### 7.5.7 Freeboard

The design discharge and design water level is based on a rainfall event with a five-year return period. To ensure that floodwater flowing in a drainage channel will not overtop the channel section at any point and cause flooding of adjacent land free board should be provided to the drainage channels as given below.

**Table 7-7 Drainage Channel Freeboard**

| Drain type | Freeboard (m) |
|---|---|
| Quaternary Drain | 0.15 |
| Tertiary Drain | 0.2 |
| Interceptor and Collector Drains | 0.20 – 0.30 |
| Main Drain | 0.30 to 0.5 |

## 7.6 Details of Drainage Channels

### i. Interceptor drains

The Interceptor drains (protection dikes) are aligned parallel to the main canal and approximately 25m away from the canal centerline. There are eight interceptor drains conveying runoff from floods arising small gullies in to the major rivers i.e. in to where their nearest cross drainage work is located.

The interceptor drains has designed as unlined earthen canals with a trapezoidal cross section with a fill right bank that is used as protection dike and the design capacity of the canal has been calculated by the Manning's flow formula. The side slope has been set to 1:2 (V: H) and manning Roughness Coefficient, 'n' = 0.025 has taken. The details of hydraulic parameters are provided on annex 3.

### ii. Collector drain

Collector drains (catchment drains) mainly follows the natural drainage channels or depressions. These drains convey surface water from several tertiary drains and runoff coming out outside the command area that passes in Cross drainage structure. The interceptor drains has designed as unlined earthen canals with a trapezoidal cross section and the design capacity of the canal has been calculated by the Manning's flow formula. The side slope has been set to 1:1.5 (V: H) and manning Roughness Coefficient, 'n' = 0.025 has taken. The details of hydraulic parameters are provided on annex 3.

### iii. Infield drains

Infield drains are planned to excavate within a command area to drain excess rainfall falling onto land and possibly control groundwater levels. Generally the infield drains are networks of quaternary and territory drains and basic for determination of drainage design discharge.

Infield drains has designed as unlined earthen canals with a trapezoidal cross section by the Manning's flow formula and manning Roughness Coefficient, 'n' = 0.025 has taken.

Quaternary drains and side slopes of 1:1 (V: H) and a freeboard has been set to 0.15m. These drains will have minimum bed width of 0.25m and the minimum water level at is set at least 0.15 mm below ground level.

Tertiary drains side slope has been set to 1:1 (V: H) and a freeboard has been set to 0.2 m. The minimum water level in Tertiary drains well be kept at is set at least 0.1 mm below the minimum water level of out falling Quaternary drains. The details of hydraulic parameters are provided on annex3.

# 8 Canal Structures

## 8.1 General

Open channel structures may be grouped as either:

- Regulating Structures (head and cross regulators structures);
- Conveyance Structures (drops, cross drainage structures) and
- Protective Structures (road crossings and escapes).

Designs of irrigation structure must take into account hydraulic, stability and structural design considerations. The types of structures on canal system are summarized in table 8-1**Error! Reference source not found.** and are discussed further in the sections below.

**Table 8-1 Type and number of Structures on Irrigation and Drainage System**

| Structure Type | Canal Type | | | | | | |
|---|---|---|---|---|---|---|---|
| | **MC** | **MC-01** | **SC and TC** | **SC, TC and QC** | **TC** | **SD,TD and QD** | **TD** |
| Cross Regulators | 5 | 2 | | | | | |
| Head Regulators | 6 | 3 | | | | | |
| Cross Drainage | 4 | | | | | | |
| Gated Off take (Division box) | | | 159 | | | | |
| Road Culvert | | | | | 71 | | 116 |
| Drop | | | | 618 | | 1053 | |
| Outfall | | | | | | 239 | |

## 8.2 Flow Control Method

For omo Valley farm irrigation project an Upstream Control is the operation method were selected. All canals will be operated 20 hours every time which helps in reducing the lag time often rose as a drawback for upstream control operation. And the client will be responsible for the Operation and management of the Main or Secondary units as well as the water delivery to the tertiary units.

A Gated Off take with Gated Cross regulator arrangement is chosen: This is widely used and typical arrangement of upstream controlled system. The gates are designed adjustable and can be manually operated automated.

## 8.3 Head and Cross regulators

A head regulator (HR) is provided at the head of off-taking channel, and its main purpose is control of discharge entering in to the off taking channel. A Cross regulator (CR) on the other hand is located at the downstream side of an off taking point on the continuing channel. Its main purpose is to head up water level so that FSL of the off-taking command can be met.

The head and cross regulating structures would be equipped with a vertical gate. The Flow under gated structure can be divided into free flow, drowned orifice flow, and closed conveyance flow. The formula for the free flow is different from that of the drowned and closed conveyance flow. As a result flow condition under the get has to be checked first.

### 8.3.1 Main Canal Cross Regulators

A gated cross regulator has been provided at all secondary canal off takes. There are four on the Main Canal (MC) and two on branch Main Canal (MC-01). Vertical lift gates will be incorporated with each structure. The entire cross regulators on main canal are design as ‘free Orifice Flow’ condition which the driving head is the difference between the upstream and downstream energy levels. The maximum driving head of 0.2m has been taken. The details main canal Head and Cross regulators are provided on the following table 8.2.

**Table 8-2 Main Canal Cross Regulators Structure Parameters**

| Reference | Off-taking Chainage (m) | Off-taking Secondary Canal | Design Discharge ($m^3/s$) | Gate Opening Size and Number (b x w-N) |
|---|---|---|---|---|
| CR1 | 3244 | SC01 | 10.16 | 2.0x2.0-3 |
| CR2 | 5830 | SC-3 | 9.62 | 1.6x1.9-3 |
| CR3 | 7497 | MC01 | 4.55 | 1.4x1.8-2 |
| CR4 | 10169 | SC-4 | 1.60 | 1.2x1.5-1 |
| CR01-1 | 627 | SC-01-1 | 1.76 | 1.4x1.7-2 |
| CR01-2 | 4247 | SC-01-2 | 0.87 | 1.1x1.4-1 |

### 8.3.2 Secondary Canal Head Regulator

A gated head regulator has been provided at all secondary canal off takes from the Main Canal. All of the head regulators are design as 'free Flow' condition with maximum driving head of 0.2m. The secondary head regulator structure will incorporate a pipe to cross under the canal embankment and the access road. The maximum length of pipe will be about 12 m. The parameters for these structures are presented on the table 8.3.

**Table 8-3 Secondary Canal Head Regulator Structures Parameters**

| Reference | Off-taking Chainage (m) | Secondary Canal | Design Discharge ($m^3/s$) | Gate Opening Size and Number (b x w-N) |
|---|---|---|---|---|
| HR1 | 3244 | SC01 | 0.96 | 1.05x1.1-1 |
| HR2 | 4789 | SC-2 | 0.29 | 1.05-1(pipe) |
| HR3 | 5830 | SC-3 | 0.20 | 0.75x0.8-1 |
| HR4 | 7497 | MC01 | 5.07 | 1.4x1.8-2 |

| | | | | |
|---|---|---|---|---|
| HR5 | 10169 | SC-4 | 2.67 | 1.6x1.55-1 |
| HR6 | 13140 | SC-5 | 1.45 | 1.2x1.45-1 |
| HR01-1 | 627 | SC01-1 | 1.94 | 1.2x1.3-2 |
| HR01-2 | 4247 | SC01-2 | 0.81 | 0.9-1(pipe) |
| HR01-3 | 4807 | SC01-3 | 0.78 | 0.9-1(pipe) |

### 8.3.3 Secondary Canal Cross Regulator

A gated cross regulator has been provided on secondary canal at downstream of all tertiary canals off take points. These structures are designed for a free flow conditions with a maximum driving head of 0.15m has been taken. The secondary cross regulator structure will incorporate a 8.0m pipe to cross from the right to the left commands.

### 8.3.4 Tertiary Canal Head Regulator

A gated head regulator has been provided at all tertiary canal off takes and these gates are simple vertical lift gates that can be operated by an individual man.The tertiary head regulator structure on the right bank of secondary canal will incorporate a 12.0m pipe to cross under the canal embankment and the access road.Amaximum driving head of 0.15mhas been considered for the design of these structures.

### 8.3.5 Tertiary Canal Cross Regulator

Tertiary canal cross regulators are similar to in secondary cross regulator, controlling the water levels upstream of quaternary off takes. These structures designed with a maximum driving head of 0.1m.

### 8.3.6 Quaternary Canal head Regulator

A gated head regulator has been provided at all quaternary canal off takes and the gates are simple vertical lift gates that can be operated by an individual man. Quaternary canal off take will be sized to discharge the irrigation stream and are designed for a maximum driving head of 0.1m.

## 8.4 Drops

Drop structures are required to dissipate the excessive energy at steep alignments to avoid erosion in unlined open-channels. These structures are designed at a high head loss for all discharges. In broad, there are three types of drop structure; chute or flume, inclined drop structure, vertical drop structure.

A vertical drop structure has a vertical wall between the control and the stilling basin. The small portion of energy loss occurs by impact of the jet on the floor. The major portion of energy loss occurs by turbulence in the stilling basin.

Vertical drop is the most common drop structure that has an aerated free-falling nappe which hits the downstream basin floor. The turbulent flow in the basin is one of the stages of energy dissipation. The most important part of the hydraulic design of the vertical drop structure is the design of the stilling basin.

Vertical drop stilling basins are characterized by a free falling jet into the basin. The free falling jet makes an impact with the basin floor and is turned into the downstream direction. The basin is equipped with an end sill. Up to 50% of the energy may be dissipated by the impact of the jet and by the turbulent circulation in the pool beneath the jet. The remainder part is dissipated by the hydraulic jump in the basin. Even if the vertical drop stilling basin seems easy to construct, but it has to be well checked on uplift of the floor by groundwater pressure.

For this project a standard drop height of 1.0m, 1.25m, 1.5m, 1.75m and 2.0m have been adapted and accordingly A range of standard vertical drop structures have been designed for secondary , tertiary and quaternary canals , respectively.

## 8.5 Road Culvert

Road Culverts structures are provided where access routes cut by tertiary canals. These will be simple concrete pipe culverts capable of passing canal discharge. The Road Culverts structures are designed based on the procedures outlined on the Irrigation and Drainage System Planning and Design Criteria Report.

## 8.6 Cross drainage structures

Cross drainage structures are provided on the main canal on locations where there are major tributaries of Omo River. The location and type of cross drainage structures have been identified and designed according to the design criteria. For detail refer Irrigation and Drainage System Planning and Design Criteria Report.

There are four cross drainage structures provided on the main canal and categorized in three types, which are pipe culvert, box culvert and inverted siphon. For hydraulic design of the cross-drainage structures is the 1 in 25 year return period peak has been adopted and The particular configuration for each is summarized in **Error! Reference source not found.**9.4.

**Table 8-4 Cross-Drainage Structures Locations and Structure Types**

| Cross-Drainage Structure | Canal Name | Chainage along MC | Design Discharge of MC | 1 in 50 year design discharge | Structure Type |
|---|---|---|---|---|---|
| | | *m* | *$m^3/s$* | *$m^3/s$* | |
| CD 1 | MC | 1218 | 10.0 | 9.4 | Box Culverts |
| CD 2 | MC | 4814 | 8.8 | 11.8 | Box Culverts |
| CD 3 | MC | 6950 | 8.6 | 22.2 | Box Culverts |
| CD 3 | MC | 11511 | 1.4 | 11.1 | Box Culverts |

# 9 Drain Structures

## 9.1 Drain Drops

Drain drops are required to keep the bed gradient of the drain in the prescribed limit of bed slope with a purpose of dissipating the energy and avoid erosion. Low masonry drops will be provided along the secondary, tertiary and quaternary drains when it is required. A standard drop height of 1.0m, 1.25m, 1.5m, 1.75m and 2.0m have been adapted and accordingly a vertical drop structures have been designed for the discharges of secondary, tertiary and quaternary drains.

## 9.2 Drain Outfalls

Drain outfall structures are required whenever s subsidiary drains pour into a bigger drain in the network and a minimum outfall (level difference) 0.15 meters should be provided. The Drops will be kept small so that earthworks in the drains are minimized, the structures will be constructed from riprap, and so that they can be easily repaired. The drop height of all drains is limited to a range of 0.5 and 2.0 m.

## 9.3 Road Culvert

Road Culverts structures are provided where access routes cut by tertiary drains. These will be simple concrete pipe culverts capable of passing canal discharge. The Road Culverts structures are designed based on the procedures outlined on the Irrigation and Drainage System Planning and Design Criteria Report.

# 10 Cost Estimates of Irrigation and Drainage System

The details of Bill of the cost estimate of irrigation and drainage system earthwork and structures for omo valley farm irrigation project Irrigation Project are presented in the bill of quantity section. The summary of project costs is presented on the following table.

**Table 10-1 Summary of the Capital Costs of Irrigation and Drainage system**

| Description | Amount ( Birr) |
|---|---|
| Main Canal-MC (CH;0m to 13140m) | 122,732,272 |
| Branch Main Canal -MC01 (CH;0m to 4807m) | 28,142,829 |
| Irrigation and Drainage system in SC-1 to SC-5 Blocks (2655ha) | 259,135,946 |
| Irrigation and Drainage system in SC-01-1 to SC-01-3 (1946ha) | 402,554,850 |
| Cross drainage culverts, Protection Dykes, and Interceptor Drains | 395,247,412 |
| **Total** | **1,207,813,310** |

# 11 References


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# 12 Annexes

## Annex 1. Net Command Area under Irrigation System

Net Command Area of Secondary Canals

| Canal Name | NIA |
|---|---|
| | ha |
| SC-1 | 472 |
| SC-2 | 141 |
| SC-3 | 100 |
| SC-4 | 1295 |
| SC-5 | 648 |
| SC-01-1 | 909 |
| SC-01-1(0) | 252 |
| SC-01-2 | 399 |
| SC-01-3 | 386 |
| Un Surveyed Area | 178 |
| **Total** | **4779** |

Net Command Area of Tertiary Canals

| Canal Name | NIA | Canal Name | NIA |
|---|---|---|---|
| | ha | | ha |
| TC-1-1 | 103.0 | TC-5-2 | 13.3 |
| TC-1-2 | 37.9 | TC-5-3 | 96.8 |
| TC-1-3 | 156.0 | TC-5-4 | 64.7 |
| TC-1-4 | 55.2 | TC-5-5 | 82.9 |
| TC-1-5 | 88.9 | TC-5-6 | 82.6 |
| TC-1-6 | 31.3 | TC-5-7 | 69.1 |
| T-2-1 | 71.2 | TC-5-8 | 69.0 |
| TC-2-2 | 69.4 | TC-5-9 | 48.1 |
| TC-3-1 | 34.6 | TC-5-10 | 69.6 |
| TC-3-2 | 35.4 | TC-01-1-1 | 299.2 |
| TC-3-3 | 30.1 | TC-01-1-2 | 112.0 |
| TC-4-1 | 78.2 | TC-01-1-3 | 209.0 |
| TC-4-2 | 59.6 | TC-01-1-4 | 232.4 |
| TC-4-3 | 189.1 | TC-01-1(0)-2 | 117.5 |
| TC-4-4 | 113.8 | TC-01-1(0)-3 | 134.4 |
| TC-4-5 | 163.1 | TC-01-2-1 | 42.5 |
| TC-4-6 | 133.8 | TC-01-2-2 | 68.0 |
| TC-4-7 | 99.3 | TC-01-2-3 | 91.0 |
| TC-4-8 | 153.2 | TC-01-2-4 | 117.9 |

| Canal Name | NIA | Canal Name | NIA |
|---|---|---|---|
| | ha | | ha |
| TC-4-9 | 39.3 | TC-01-2-5 | 80.0 |
| TC-4-10 | 171.7 | TC-01-3-4 | 67.9 |
| TC-4-11 | 93.6 | TC-01-3-5 | 74.2 |
| TC-5-1 | 51.4 | TC-01-3-6 | 80.8 |

Net Command Area of Quaternary Canals

| Canal Name | NIA | Canal Name | NIA | Canal Name | NIA |
|---|---|---|---|---|---|
| | ha | | ha | | ha |
| QC-1-1-1 | 46.32 | QC-4-8-2 | 34.18 | QC-01-1-2-2 | 40.24 |
| QC-1-1-2 | 14.11 | QC-4-8-3 | 60 | QC-01-1-2-3 | 6.89 |
| QC-1-1-3 | 42.61 | QC-4-8-4 | 29.04 | QC-01-1-2-4 | 21.51 |
| QC-1-2-1 | 37.93 | QC-4-9-1 | 39.34 | QC-01-1-2-5 | 9.25 |
| QC-1-3-1 | 60 | QC-4-10-1 | 30 | QC-01-1-3-1 | 29.29 |
| QC-1-3-2 | 34.65 | QC-4-10-2 | 55.19 | QC-01-1-3-2 | 66.43 |
| QC-1-3-3 | 61.32 | QC-4-10-3 | 60 | QC-01-1-3-3 | 29.44 |
| QC-1-4-1 | 55.15 | QC-4-10-4 | 26.48 | QC-01-1-3-4 | 53.81 |
| QC-1-5-1 | 57.37 | QC-4-11-1 | 15.54 | QC-01-1-3-5 | 30.06 |
| QC-1-5-2 | 31.54 | QC-4-11-2 | 47.89 | QC-01-1-4-1 | 81.83 |
| QC-1-6-1 | 31.3 | QC-4-11-3 | 30.14 | QC-01-1-4-2 | 19.52 |
| QC-2-1-1 | 44.33 | QC-5-1-1 | 22.54 | QC-01-1-4-3 | 62.91 |
| QC-2-1-2 | 26.82 | QC-5-1-2 | 28.87 | QC-01-1-4-1(0) | 68.1 |
| QC-2-2-1 | 38.2 | QC-5-2-1 | 13.32 | QC-01-1-5 | 56.04 |
| QC-2-2-2 | 31.18 | QC-5-3-1 | 60 | QC-01-1(0)-2-1 | 60.89 |
| QC-3-1-1 | 34.64 | QC-5-3-2 | 36.84 | QC-01-1(0)-2-2 | 56.6 |
| QC-3-2-1 | 35.37 | QC-5-4-1 | 15.53 | QC-01-1(0)-3-1 | 25.86 |
| QC-3-3-1 | 30.14 | QC-5-4-2 | 42.5 | QC-01-1(0)-3-2 | 26.67 |
| QC-4-1-1 | 27.89 | QC-5-4-3 | 6.63 | QC-01-1(0)-3-3 | 58.9 |
| QC-4-1-2 | 30.78 | QC-5-5-1 | 60 | QC-01-1(0)-3-4 | 22.97 |
| QC-4-1-3 | 10.95 | QC-5-5-2 | 22.94 | QC-01-2-1 | 42.51 |
| QC-4-1-4 | 8.6 | QC-5-6-1 | 35.17 | QC-01-2-2-1 | 41.48 |
| QC-4-2-1 | 37.56 | QC-5-6-2 | 47.46 | QC-01-2-2-2 | 26.49 |
| QC-4-2-2 | 22.02 | QC-5-7-1 | 60 | QC-01-2-3-1 | 67.51 |
| QC-4-3-1 | 56.03 | QC-5-7-2 | 9.05 | QC-01-2-3-2 | 23.47 |
| QC-4-3-2 | 59.56 | QC-5-8-1 | 9.86 | QC-01-2-4-1 | 93.65 |
| QC-4-3-3-1 | 31.53 | QC-5-8-2 | 59.12 | QC-01-2-4-2 | 24.2 |
| QC-4-3-3-2 | 30 | QC-5-9-1 | 48.13 | QC-01-2-5-1 | 27.66 |
| QC-4-3-4 | 12 | QC-5-10-1 | 51.09 | QC-01-2-5-2 | 32.54 |
| QC-4-4-1 | 22.69 | QC-5-10-2 | 18.48 | QC-01-2-5-3 | 19.81 |
| QC-4-4-2 | 60 | QC-01-1-1-1 | 24.09 | QC-01-3-1 | 38.47 |
| QC-4-4-3 | 31.11 | QC-01-1-1-2 | 38.42 | QC-01-3-2 | 55.47 |
| QC-4-5-1 | 63.27 | QC-01-1-1-3 | 31.23 | QC-01-3-3 | 69.48 |
| QC-4-5-1 | 59.51 | QC-01-1-1-4 | 49.2 | QC-01-3-4-1 | 23.91 |
| QC-4-5-1 | 40.28 | QC-01-1-1-5 | 48.65 | QC-01-3-4-2 | 43.99 |
| QC-4-6-1 | 43.68 | QC-01-1-1-6 | 26.12 | QC-01-3-5-1 | 19.88 |

| Canal Name | NIA | Canal Name | NIA | Canal Name | NIA |
|---|---|---|---|---|---|
| | ha | | ha | | ha |
| QC-4-6-2 | 60 | QC-01-1-1-7 | 29.73 | QC-01-3-5-2 | 54.34 |
| QC-4-6-3 | 30.08 | QC-01-1-1-8 | 21.87 | QC-01-3-6-1 | 21.2 |
| QC-4-7-1 | 68.49 | QC-01-1-1-9 | 29.9 | QC-01-3-6-2 | 44.47 |
| QC-4-7-2 | 30.77 | QC-01-1-2-1 | 34.09 | QC-01-3-6-3 | 15.14 |
| QC-4-8-1 | 30.01 | | | | |

## Annex 2 Details of Hydraulic Design Parameters of Irrigation Canals

### Hydraulic Design Parameters of Main Canal (0 to13140m)

| Reach | Offtaking Canal | Required Discharge | Roughness Coefficient | F.S.D | F.B | Bed Slope | Bed width | Side slope | Bank width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M | | $m^3/s$ | - | m | m | 1m/m | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| 0-3244 | SC-01 | **10.0** | 0.020 | 2.01 | 0.50 | 5000.0 | 6.3 | 0.00 | 3.00 | 13.23 | 10.50 | 1.26 | 0.82 | **10.0** | 4.16 | **5000** |
| 3244-3900 | | **9.1** | 0.020 | 1.97 | 0.50 | 5000.0 | 6.2 | 0.00 | 3.00 | 15.60 | 11.86 | 1.32 | 0.85 | **9.1** | 4.02 | **4528** |
| 3900-4789 | SC-02 | **9.1** | 0.0250 | 1.71 | 0.50 | 5000.0 | 6.9 | 1.50 | 3.00 | 16.05 | 12.97 | 1.24 | 0.65 | **9.1** | 4.02 | **4528** |
| 4789-5830 | SC-03 | **8.8** | 0.0250 | 1.67 | 0.50 | 4500.0 | 6.6 | 1.50 | 3.00 | 15.05 | 12.54 | 1.20 | 0.67 | **8.8** | 3.98 | **4387** |
| 5830-7497 | MC01 | **8.6** | 0.0250 | 1.66 | 0.50 | 4500.0 | 6.5 | 1.50 | 3.00 | 14.78 | 12.41 | 1.19 | 0.67 | **8.6** | 3.94 | **4287** |
| 7497-10169 | SC-04 | **4.1** | 0.0250 | 1.36 | 0.50 | 4500.0 | 4.1 | 1.50 | 3.00 | 8.28 | 8.96 | 0.92 | 0.57 | **4.1** | 3.03 | **2027** |
| 10169-13140 | SC-05 | **1.4** | 0.0250 | 1.02 | 0.50 | 4500.0 | 2.1 | 1.50 | 3.00 | 3.72 | 5.79 | 0.64 | 0.44 | **1.4** | 2.10 | **713** |

### Hydraulic Design Parameters of Branch Main Canal MC01 (0 to4807m)

| Reach | Offtaking Canal | Required Discharge | Roughness Coefficient | F.S.D | F.B | Bed Slope | Bed width | Side slope | Bank width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-627 | SC-01-1 | **4.673** | 0.0250 | 1.40 | 0.50 | 5000.0 | 4.2 | 1.50 | 3.00 | 8.80 | 9.24 | 0.95 | 0.55 | **4.670** | 3.02 | **2082.30** |
| 627-4247 | SC-01-2 | **1.763** | 0.0250 | 1.07 | 0.50 | 5000.0 | 2.3 | 1.50 | 3.00 | 4.17 | 6.15 | 0.68 | 0.44 | **1.760** | 2.15 | **785.67** |
| 4247-4807 | SC-01-3 | **0.867** | 0.0250 | 0.87 | 0.40 | 5000.0 | 1.5 | 1.50 | 3.00 | 2.43 | 4.62 | 0.53 | 0.37 | **0.860** | 1.67 | **386.35** |

### Hydraulic Design Parameters of SC-MC

| Reach | Offtaking Canal | Required Discharge | Roughness Coefficient | F.S.D | F.B | Bed Slope | Bed width | Side slope | Bank width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | Diffe rence | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m | | $m^3/s$ | - | m | m | 1m/m | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | $m^3/s$ | - | ha |
| **SC01 (0 to1393m)** | | | | | | | | | | | | | | | | | |
| 0-23 | TC-1-1&TC-1-2 | **0.958** | 0.0250 | 0.82 | 0.40 | 3000.0 | 1.4 | 1.50 | 1.50 | 2.15 | 4.36 | 0.49 | 0.46 | **0.984** | 0.03 | 1.73 | **472.30** |
| 23-637 | TC-1-3&TC-1-4 | **0.672** | 0.0250 | 0.71 | 0.40 | 2500.0 | 1.1 | 1.50 | 1.50 | 1.54 | 3.66 | 0.42 | 0.45 | **0.691** | 0.02 | 1.53 | **331.33** |
| 637-1393 | TC-1-5&TC1-6 | **0.244** | 0.0250 | 0.51 | 0.30 | 2000.0 | 0.5 | 1.50 | 1.50 | 0.66 | 2.37 | 0.28 | 0.38 | **0.251** | 0.01 | 1.07 | **120.21** |
| **SC02 (0 to 813m)** | | | | | | | | | | | | | | | | | |
| 0-22 | TC-2-1 | **0.285** | 0.0250 | 0.55 | 0.30 | 2500.0 | 0.63 | 1.50 | 1.50 | 0.81 | 2.62 | 0.31 | 0.36 | **0.294** | 0.009 | 1.13 | **140.53** |
| 22-813 | TC-2-2 | **0.141** | 0.0250 | 0.42 | 0.30 | 2000.0 | 0.42 | 1.50 | 1.50 | 0.44 | 1.93 | 0.23 | 0.33 | **0.146** | 0.006 | 1.00 | **69.38** |
| **SC03 (0 to 486m)** | | | | | | | | | | | | | | | | | |
| 0-25 | TC-3-1&TC-3-2 | **0.203** | 0.0250 | 0.50 | 0.30 | 2000.0 | 0.50 | 1.50 | 1.50 | 0.62 | 2.30 | 0.27 | 0.37 | **0.234** | 0.031 | 1.01 | **100.15** |
| 25-486 | TC-3-3 | **0.061** | 0.0250 | 0.29 | 0.30 | 1500.0 | 0.29 | 1.50 | 1.50 | 0.21 | 1.34 | 0.16 | 0.30 | **0.064** | 0.003 | 1.00 | **30.14** |
| **SC04 (0 to 3426m)** | | | | | | | | | | | | | | | | | |
| 0-22 | TC-4-1&TC-4-2 | **2.665** | 0.0250 | 1.09 | 0.50 | 3000.0 | 2.70 | 1.50 | 1.50 | 4.70 | 6.61 | 0.71 | 0.58 | **2.734** | 0.069 | 2.48 | **1314.18** |
| 22-402 | TC-4-3&TC-4-4 | **2.346** | 0.0250 | 1.04 | 0.50 | 2900.0 | 2.47 | 1.50 | 1.50 | 4.21 | 6.23 | 0.68 | 0.57 | **2.408** | 0.062 | 2.37 | **1156.81** |

| Reach | Offtaking Canal | Required Discharge | Roughness Coefficient | F.S.D | F.B | Bed Slope | Bed width | Side slope | Bank width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | Difference | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m | | $m^3/s$ | - | m | m | 1m/m | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | $m^3/s$ | - | ha |
| 402-1158 | TC-4-5&TC-4-6 | **1.732** | 0.0250 | 0.95 | 0.50 | 2800.0 | 2.03 | 1.50 | 1.50 | 3.30 | 5.47 | 0.60 | 0.54 | **1.778** | 0.046 | 2.13 | **853.89** |
| 1158-1914 | TC-4-7&TC-4-8 | **1.130** | 0.0250 | 0.84 | 0.50 | 2700.0 | 1.54 | 1.50 | 1.50 | 2.35 | 4.56 | 0.51 | 0.49 | **1.160** | 0.030 | 1.84 | **557.07** |
| 1914-2670 | TC-4-9&TC-4-10 | **0.618** | 0.0250 | 0.70 | 0.40 | 2600.0 | 1.04 | 1.50 | 1.50 | 1.46 | 3.56 | 0.41 | 0.43 | **0.634** | 0.016 | 1.49 | **304.58** |
| 2670-3426 | TC-4-11 | **0.190** | 0.0250 | 0.49 | 0.30 | 2500.0 | 0.49 | 1.50 | 1.50 | 0.60 | 2.25 | 0.26 | 0.33 | **0.196** | 0.007 | 1.00 | **93.57** |
| **SC05 (0 to 2497m)** | | | | | | | | | | | | | | | | | |
| 0-25 | TC-5-1&TC-5-2 | **1.445** | 0.0250 | 0.92 | 0.50 | 3000.0 | 1.84 | 1.50 | 1.50 | 2.95 | 5.14 | 0.57 | 0.50 | **1.483** | 0.038 | 2.00 | **712.66** |
| 25-229 | TC-5-3&TC-5-4 | **1.259** | 0.0250 | 0.88 | 0.50 | 2900.0 | 1.67 | 1.50 | 1.50 | 2.62 | 4.83 | 0.54 | 0.49 | **1.292** | 0.034 | 1.91 | **620.65** |
| 229-985 | TC-5-5&TC-5-6 | **0.891** | 0.0250 | 0.79 | 0.40 | 2800.0 | 1.33 | 1.50 | 1.50 | 1.99 | 4.18 | 0.48 | 0.46 | **0.915** | 0.024 | 1.69 | **439.53** |
| 985-1741 | TC-5-7&TC-5-8 | **0.548** | 0.0250 | 0.68 | 0.40 | 2700.0 | 0.97 | 1.50 | 1.50 | 1.36 | 3.43 | 0.40 | 0.42 | **0.564** | 0.015 | 1.43 | **270.44** |
| 1741-2497 | TC-5-9&TC-5-10 | **0.239** | 0.0250 | 0.53 | 0.30 | 2600.0 | 0.56 | 1.50 | 1.50 | 0.71 | 2.46 | 0.29 | 0.34 | **0.245** | 0.006 | 1.07 | **117.70** |
| **SC01-1 (0 to 2315m)** | | | | | | | | | | | | | | | | | |
| 0~25 | TC-01-1-1 & TC-01-1-2 | **2.630** | 0.0250 | 1.08 | 0.50 | 3000.0 | 2.7 | 1.50 | 1.50 | 4.65 | 6.58 | 0.71 | 0.58 | **2.697** | 0.07 | 2.47 | **1296.63** |
| 25~724 | TC-01-1-3 & SC-01-1(0) | **1.783** | 0.0250 | 0.94 | 0.50 | 2500.0 | 2.0 | 1.50 | 1.50 | 3.23 | 5.41 | 0.60 | 0.57 | **1.830** | 0.05 | 2.15 | **879.23** |
| 724~1713 | TC-01-1-4 | **0.592** | 0.0250 | 0.66 | 0.40 | 2000.0 | 1.0 | 1.50 | 1.50 | 1.29 | 3.34 | 0.39 | 0.47 | **0.608** | 0.02 | 1.47 | **292.00** |
| 1713~3055 | QC-01-1-5 | **0.114** | 0.0250 | 0.39 | 0.30 | 2000.0 | 0.4 | 1.50 | 1.50 | 0.37 | 1.78 | 0.21 | 0.32 | **0.118** | 0.00 | 1.00 | **56.04** |
| **SC01-1(0) (0 to 2315m)** | | | | | | | | | | | | | | | | | |
| 0~22 | QC-01-1(0)-0 | **0.693** | 0.0250 | 0.72 | 0.40 | 2500.0 | 1.11 | 1.50 | 1.50 | 1.57 | 3.70 | 0.43 | 0.45 | **0.712** | 0.019 | 1.55 | **341.69** |
| 22~865 | TC-01-1(0)-1 | **0.632** | 0.0250 | 0.67 | 0.40 | 2000.0 | 1.01 | 1.50 | 1.50 | 1.35 | 3.42 | 0.39 | 0.48 | **0.649** | 0.016 | 1.50 | **311.83** |
| 865~1434 | TC-01-1(0)-2 | **0.520** | 0.0250 | 0.63 | 0.40 | 2000.0 | 0.89 | 1.50 | 1.50 | 1.17 | 3.17 | 0.37 | 0.46 | **0.535** | 0.014 | 1.40 | **256.58** |
| 1434~2315 | TC-01-1(0)-3 | **0.273** | 0.0250 | 0.52 | 0.30 | 2000.0 | 0.58 | 1.50 | 1.50 | 0.72 | 2.47 | 0.29 | 0.39 | **0.280** | 0.008 | 1.12 | **134.40** |
| **SC01-2 (0 to 3597m)** | | | | | | | | | | | | | | | | | |
| 0~20 | TC-01-2-1 | **0.810** | 0.0250 | 0.75 | 0.40 | 2500.0 | 1.23 | 1.50 | 1.50 | 1.77 | 3.94 | 0.45 | 0.47 | **0.831** | 0.022 | 1.63 | **399.32** |
| 20~560 | TC-01-2-2 | **0.724** | 0.0250 | 0.73 | 0.40 | 2500.0 | 1.14 | 1.50 | 1.50 | 1.63 | 3.77 | 0.43 | 0.46 | **0.743** | 0.020 | 1.57 | **356.81** |

| Reach | Offtaking Canal | Required Discharge | Roughness Coefficient | F.S.D | F.B | Bed Slope | Bed width | Side slope | Bank width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | Difference | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m | | $m^3/s$ | - | m | m | 1m/m | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | $m^3/s$ | - | ha |
| 560~1309 | TC-01-2-3 | **0.586** | 0.0250 | 0.66 | 0.40 | 2000.0 | 0.96 | 1.50 | 1.50 | 1.27 | 3.32 | 0.38 | 0.47 | **0.601** | 0.016 | 1.46 | **288.84** |
| 1309~2404 | TC-01-2-4 | **0.401** | 0.0250 | 0.59 | 0.30 | 2000.0 | 0.75 | 1.50 | 1.50 | 0.96 | 2.87 | 0.33 | 0.43 | **0.412** | 0.010 | 1.28 | **197.86** |
| 2404~3597 | TC-01-2-5 | **0.162** | 0.0250 | 0.44 | 0.30 | 2000.0 | 0.44 | 1.50 | 1.50 | 0.49 | 2.04 | 0.24 | 0.35 | **0.169** | 0.007 | 1.00 | **80.01** |
| **SC01-3 (0 to 3496m)** | | | | | | | | | | | | | | | | | |
| 0~27 | TC-01-3-1 | **0.784** | 0.0250 | 0.71 | 0.40 | 2000.0 | 1.15 | 1.50 | 1.50 | 1.59 | 3.73 | 0.43 | 0.51 | **0.805** | 0.021 | 1.62 | **386.35** |
| 27~582 | TC-01-3-2 | **0.706** | 0.0250 | 0.66 | 0.40 | 1500.0 | 1.02 | 1.50 | 1.50 | 1.32 | 3.39 | 0.39 | 0.55 | **0.725** | 0.019 | 1.56 | **347.88** |
| 582~1296 | TC-01-3-3 | **0.593** | 0.0250 | 0.62 | 0.40 | 1500.0 | 0.91 | 1.50 | 1.50 | 1.16 | 3.17 | 0.36 | 0.53 | **0.609** | 0.016 | 1.47 | **292.41** |
| 1296~2067 | TC-01-3-4 | **0.452** | 0.0250 | 0.58 | 0.30 | 1500.0 | 0.77 | 1.50 | 1.50 | 0.94 | 2.85 | 0.33 | 0.49 | **0.464** | 0.012 | 1.33 | **222.93** |
| 2067~2700 | TC-01-3-5 | **0.314** | 0.0250 | 0.52 | 0.30 | 1500.0 | 0.61 | 1.50 | 1.50 | 0.71 | 2.47 | 0.29 | 0.45 | **0.323** | 0.009 | 1.17 | **155.03** |
| 2700~3496 | TC-01-3-6 | **0.164** | 0.0250 | 0.42 | 0.30 | 1500.0 | 0.42 | 1.50 | 1.50 | 0.44 | 1.93 | 0.23 | 0.38 | **0.169** | 0.005 | 1.00 | **80.81** |

## Hydraulic Design Parameters of Tertiary Canal (TC)

| Reach | Offtaking Canal | Required Discharge | Roughness Coefficient | F.S.D | F.B | Bed Slope | Bed width | Side slope | Bank width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m | | $m^3/s$ | - | m | m | 1m/m | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| 0-1298 | TC-1-1 | **0.188** | 0.0250 | 0.54 | 0.20 | 2500.0 | 0.5 | 1.00 | 1.00 | 0.57 | 2.05 | 0.28 | 0.34 | **0.196** | 1.00 | **103.04** |
| 0-326 | TC-1-2 | **0.069** | 0.0250 | 0.33 | 0.20 | 1500.0 | 0.33 | 1.00 | 1.00 | 0.22 | 1.28 | 0.17 | 0.32 | **0.072** | 1.00 | **37.93** |
| 0~1496 | TC-1-3 | **0.284** | 0.0250 | 0.62 | 0.20 | 3000.0 | 0.71 | 1.00 | 1.00 | 0.83 | 2.47 | 0.34 | 0.35 | **0.292** | 1.13 | **155.97** |
| 0~370 | TC-1-4 | **0.101** | 0.0250 | 0.41 | 0.20 | 2000.0 | 0.41 | 1.00 | 1.00 | 0.33 | 1.55 | 0.21 | 0.32 | **0.105** | 1.00 | **55.15** |
| 0~1107 | TC-1-5 | **0.162** | 0.0250 | 0.51 | 0.20 | 2500.0 | 0.51 | 1.00 | 1.00 | 0.51 | 1.93 | 0.26 | 0.33 | **0.168** | 1.00 | **88.91** |
| 0~402 | TC-1-6 | **0.057** | 0.0250 | 0.31 | 0.20 | 1500.0 | 0.31 | 1.00 | 1.00 | 0.19 | 1.19 | 0.16 | 0.31 | **0.060** | 1.00 | **31.30** |
| 0~626 | TC-2-1 | **0.130** | 0.0250 | 0.46 | 0.20 | 2500.0 | 0.46 | 1.00 | 1.00 | 0.43 | 1.78 | 0.24 | 0.31 | **0.135** | 1.00 | **71.15** |
| 0~616 | TC-2-2 | **0.112** | 0.0250 | 0.47 | 0.20 | 2700.0 | 0.47 | 1.00 | 1.00 | 0.44 | 1.79 | 0.24 | 0.30 | **0.132** | 1.00 | **69.38** |
| 0~457 | TC-3-1 | **0.063** | 0.0250 | 0.32 | 0.20 | 1500.0 | 0.32 | 1.00 | 1.00 | 0.21 | 1.24 | 0.17 | 0.32 | **0.066** | 1.00 | **34.64** |
| 0~485 | TC-3-2 | **0.065** | 0.0250 | 0.33 | 0.20 | 1500.0 | 0.33 | 1.00 | 1.00 | 0.21 | 1.25 | 0.17 | 0.32 | **0.067** | 1.00 | **35.37** |
| 0~400 | TC-3-3 | **0.055** | 0.0250 | 0.31 | 0.20 | 1500.0 | 0.31 | 1.00 | 1.00 | 0.19 | 1.18 | 0.16 | 0.30 | **0.057** | 1.00 | **30.14** |
| 0~2659 | TC-4-1 | **0.178** | 0.0250 | 0.56 | 0.20 | 3500.0 | 0.56 | 1.00 | 1.00 | 0.62 | 2.14 | 0.29 | 0.30 | **0.186** | 1.00 | **97.79** |
| 0~876 | TC-4-2 | **0.109** | 0.0250 | 0.44 | 0.20 | 2500.0 | 0.44 | 1.00 | 1.00 | 0.38 | 1.67 | 0.23 | 0.30 | **0.113** | 1.00 | **59.58** |
| 0~2524 | TC-4-3 | **0.345** | 0.0250 | 0.66 | 0.20 | 3000.0 | 0.80 | 1.00 | 1.00 | 0.96 | 2.66 | 0.36 | 0.37 | **0.355** | 1.21 | **189.12** |
| 0~998 | TC-4-4 | **0.208** | 0.0250 | 0.60 | 0.20 | 3900.0 | 0.61 | 1.00 | 1.00 | 0.72 | 2.30 | 0.31 | 0.30 | **0.214** | 1.02 | **113.80** |
| 0~2032 | TC-4-5 | **0.297** | 0.0250 | 0.65 | 0.20 | 3500.0 | 0.75 | 1.00 | 1.00 | 0.91 | 2.59 | 0.35 | 0.34 | **0.307** | 1.15 | **163.06** |
| 0~1277 | TC-4-6 | **0.244** | 0.0250 | 0.58 | 0.20 | 2500.0 | 0.62 | 1.00 | 1.00 | 0.69 | 2.25 | 0.31 | 0.36 | **0.252** | 1.07 | **133.76** |
| 0~1304 | TC-4-7 | **0.181** | 0.0250 | 0.56 | 0.20 | 3500.0 | 0.56 | 1.00 | 1.00 | 0.63 | 2.15 | 0.29 | 0.30 | **0.188** | 1.00 | **99.26** |
| 0~1557 | TC-4-8 | **0.279** | 0.0250 | 0.62 | 0.20 | 3000.0 | 0.70 | 1.00 | 1.00 | 0.82 | 2.45 | 0.33 | 0.35 | **0.287** | 1.13 | **153.23** |
| 0~405 | TC-4-9 | **0.072** | 0.0250 | 0.35 | 0.20 | 1800.0 | 0.35 | 1.00 | 1.00 | 0.25 | 1.34 | 0.18 | 0.30 | **0.074** | 1.00 | **39.34** |
| 0~1837 | TC-4-10 | **0.313** | 0.0250 | 0.68 | 0.20 | 4250.0 | 0.80 | 1.00 | 1.00 | 1.01 | 2.73 | 0.37 | 0.32 | **0.321** | 1.17 | **171.67** |

| Reach | Offtaking Canal | Required Discharge | Roughness Coefficient | F.S.D | F.B | Bed Slope | Bed width | Side slope | Bank width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m | | $m^3/s$ | - | m | m | 1m/m | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| 0~1706 | TC-4-11 | **0.171** | 0.0250 | 0.52 | 0.20 | 2500.0 | 0.52 | 1.00 | 1.00 | 0.53 | 1.97 | 0.27 | 0.33 | **0.177** | 1.00 | **93.57** |
| 0~1233 | TC-5-1 | **0.094** | 0.0250 | 0.40 | 0.20 | 2200.0 | 0.40 | 1.00 | 1.00 | 0.32 | 1.54 | 0.21 | 0.30 | **0.098** | 1.00 | **51.41** |
| 0~1057 | TC-5-2 | **0.074** | 0.0250 | 0.36 | 0.20 | 1900.0 | 0.36 | 1.00 | 1.00 | 0.26 | 1.37 | 0.19 | 0.30 | **0.077** | 1.00 | **40.60** |
| 0~1100 | TC-5-3 | **0.177** | 0.0250 | 0.49 | 0.20 | 1800.0 | 0.49 | 1.00 | 1.00 | 0.48 | 1.88 | 0.26 | 0.38 | **0.183** | 1.00 | **96.84** |
| 0~888 | TC-5-4 | **0.154** | 0.0250 | 0.48 | 0.20 | 2000.0 | 0.48 | 1.00 | 1.00 | 0.45 | 1.82 | 0.25 | 0.35 | **0.160** | 1.00 | **84.28** |
| 0~816 | TC-5-5 | **0.151** | 0.0250 | 0.51 | 0.20 | 3000.0 | 0.51 | 1.00 | 1.00 | 0.52 | 1.95 | 0.27 | 0.30 | **0.157** | 1.00 | **82.94** |
| 0~786 | TC-5-6 | **0.157** | 0.0274 | 0.52 | 0.20 | 2500.0 | 0.52 | 1.00 | 1.00 | 0.54 | 1.98 | 0.27 | 0.31 | **0.163** | 1.00 | **86.15** |
| 0~816 | TC-5-7 | **0.126** | 0.0250 | 0.47 | 0.20 | 2700.0 | 0.47 | 1.00 | 1.00 | 0.44 | 1.79 | 0.24 | 0.30 | **0.131** | 1.00 | **69.05** |
| 0~783 | TC-5-8 | **0.153** | 0.0250 | 0.51 | 0.20 | 3000.0 | 0.51 | 1.00 | 1.00 | 0.52 | 1.96 | 0.27 | 0.30 | **0.159** | 1.00 | **83.69** |
| 0~405 | TC-5-9 | **0.088** | 0.0250 | 0.39 | 0.20 | 2000.0 | 0.39 | 1.00 | 1.00 | 0.30 | 1.48 | 0.20 | 0.31 | **0.091** | 1.00 | **48.13** |
| 0~874 | TC-5-10 | **0.127** | 0.0250 | 0.46 | 0.20 | 2500.0 | 0.46 | 1.00 | 1.00 | 0.43 | 1.77 | 0.24 | 0.31 | **0.132** | 1.00 | **69.57** |
| 0-1298 | TC-01-1-1 | **0.552** | 0.0250 | 0.73 | 0.20 | 2500.0 | 1.0 | 1.00 | 1.00 | 1.28 | 3.09 | 0.41 | 0.44 | **0.567** | 1.43 | **302.39** |
| 0-2317 | TC-01-1-2 | **0.210** | 0.0250 | 0.50 | 0.20 | 1500.0 | 0.51 | 1.00 | 1.00 | 0.51 | 1.93 | 0.26 | 0.42 | **0.216** | 1.02 | **115.01** |
| 0-4028 | TC-01-1-3 | **0.448** | 0.0250 | 0.77 | 0.20 | 4750.0 | 1.03 | 1.00 | 1.00 | 1.39 | 3.21 | 0.43 | 0.33 | **0.460** | 1.33 | **245.54** |
| 0~370 | TC-01-1-4 | **0.430** | 0.0250 | 0.65 | 0.20 | 2000.0 | 0.85 | 1.00 | 1.00 | 0.97 | 2.69 | 0.36 | 0.45 | **0.442** | 1.31 | **235.96** |
| 0~626 | TC-01-1(0)-1 | **0.101** | 0.0250 | 0.41 | 0.20 | 2000.0 | 0.41 | 1.00 | 1.00 | 0.33 | 1.56 | 0.21 | 0.32 | **0.105** | 1.00 | **55.25** |
| 0-1102 | TC-01-1(0)-2 | **0.223** | 0.0250 | 0.51 | 0.20 | 1500.0 | 0.53 | 1.00 | 1.00 | 0.53 | 1.98 | 0.27 | 0.43 | **0.230** | 1.04 | **122.18** |
| 0-1628 | TC-01-1(0)-3 | **0.245** | 0.0250 | 0.62 | 0.20 | 3500.0 | 0.66 | 1.00 | 1.00 | 0.79 | 2.40 | 0.33 | 0.32 | **0.253** | 1.08 | **134.40** |
| 0-418 | TC-01-2-1 | **0.078** | 0.0250 | 0.37 | 0.20 | 2000.0 | 0.37 | 1.00 | 1.00 | 0.27 | 1.41 | 0.19 | 0.30 | **0.081** | 1.00 | **42.51** |
| 0-519 | TC-01-2-2 | **0.124** | 0.0250 | 0.47 | 0.20 | 2700.0 | 0.47 | 1.00 | 1.00 | 0.44 | 1.79 | 0.24 | 0.30 | **0.132** | 1.00 | **67.97** |
| 0-915 | TC-01-2-3 | **0.166** | 0.0250 | 0.52 | 0.20 | 2700.0 | 0.52 | 1.00 | 1.00 | 0.54 | 1.98 | 0.27 | 0.32 | **0.172** | 1.00 | **90.98** |
| 0-811 | TC-01-2-4 | **0.215** | 0.0250 | 0.58 | 0.20 | 3250.0 | 0.60 | 1.00 | 1.00 | 0.69 | 2.25 | 0.31 | 0.32 | **0.221** | 1.03 | **117.85** |
| 0-534 | TC-01-2-5 | **0.146** | 0.0250 | 0.49 | 0.20 | 2700.0 | 0.49 | 1.00 | 1.00 | 0.49 | 1.89 | 0.26 | 0.31 | **0.152** | 1.00 | **80.01** |

| Reach | Offtaking Canal | Required Discharge | Roughness Coefficient | F.S.D | F.B | Bed Slope | Bed width | Side slope | Bank width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m | | $m^3/s$ | - | m | m | 1m/m | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| 0-213 | TC-01-3-1 | **0.070** | 0.0250 | 0.35 | 0.20 | 1750.0 | 0.35 | 1.00 | 1.00 | 0.24 | 1.32 | 0.18 | 0.31 | **0.073** | 1.00 | **38.47** |
| 0-328 | TC-01-3-2 | **0.101** | 0.0250 | 0.41 | 0.20 | 2000.0 | 0.41 | 1.00 | 1.00 | 0.33 | 1.56 | 0.21 | 0.32 | **0.105** | 1.00 | **55.47** |
| 0-503 | TC-01-3-3 | **0.127** | 0.0250 | 0.42 | 0.20 | 1500.0 | 0.42 | 1.00 | 1.00 | 0.35 | 1.60 | 0.22 | 0.38 | **0.132** | 1.00 | **69.48** |
| 0-560 | TC-01-3-4 | **0.124** | 0.0250 | 0.46 | 0.20 | 2500.0 | 0.46 | 1.00 | 1.00 | 0.42 | 1.75 | 0.24 | 0.31 | **0.129** | 1.00 | **67.90** |
| 0-735 | TC-01-3-5 | **0.135** | 0.0250 | 0.43 | 0.20 | 1500.0 | 0.43 | 1.00 | 1.00 | 0.37 | 1.64 | 0.22 | 0.38 | **0.140** | 1.00 | **74.22** |
| 0-1018 | TC-01-3-6 | **0.147** | 0.0250 | 0.44 | 0.20 | 1500.0 | 0.44 | 1.00 | 1.00 | 0.39 | 1.69 | 0.23 | 0.39 | **0.152** | 1.00 | **80.81** |

## Annex 3. Details of Hydraulic Design Parameters of Drainage Canals

### Hydraulic Design Parameters of Interceptor Drains (ID)

| CH | Canal | Required Discharge | Roughness Coefficient | F.S.D | Bed Slope | Bed width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $m^3/s$ | | m | | m | $m^2$ | m | m | m/s | $m^3/s$ | |
| 950 | ID1 | **2.350** | 0.0250 | 0.92 | 2000.0 | 2.2 | 3.73 | 6.33 | 0.59 | 0.63 | **2.350** | 2.37 |
| 557 | ID2 | **4.700** | 0.0250 | 1.17 | 2500.0 | 3.5 | 6.90 | 8.79 | 0.79 | 0.68 | **4.700** | 3.03 |
| 600 | | **9.400** | 0.0250 | 1.42 | 2500.0 | 5.5 | 11.77 | 11.81 | 1.00 | 0.80 | **9.400** | 3.86 |
| 1994 | ID3 | **4.700** | 0.0250 | 1.17 | 2500.0 | 3.5 | 6.90 | 8.79 | 0.79 | 0.68 | **4.700** | 3.03 |
| 1644 | ID4 | **5.900** | 0.0250 | 1.27 | 2750.0 | 4.2 | 8.52 | 9.85 | 0.87 | 0.69 | **5.900** | 3.28 |
| 1684 | | **11.800** | 0.0250 | 1.65 | 4000.0 | 6.9 | 16.75 | 14.24 | 1.18 | 0.70 | **11.800** | 4.18 |
| 1033 | ID5 | **5.900** | 0.0250 | 1.42 | 5000.0 | 4.7 | 10.66 | 11.01 | 0.97 | 0.55 | **5.900** | 3.28 |
| 1138 | ID6 | **4.300** | 0.0250 | 1.18 | 3000.0 | 3.5 | 6.90 | 8.76 | 0.79 | 0.62 | **4.300** | 2.93 |
| 1013 | ID7 | **2.70** | 0.0250 | 1.04 | 3000.0 | 2.6 | 4.83 | 7.22 | 0.67 | 0.56 | **2.700** | 2.49 |
| 2608 | | **11.20** | 0.0250 | 1.58 | 3500.0 | 6.5 | 15.30 | 13.57 | 1.13 | 0.73 | **11.200** | 4.10 |
| 3173 | | **14.30** | 0.0250 | 1.81 | 5000.0 | 8.1 | 21.14 | 16.16 | 1.31 | 0.68 | **14.300** | 4.47 |
| 4075 | | **16.90** | 0.0250 | 1.92 | 5500.0 | 9.1 | 24.94 | 17.72 | 1.41 | 0.68 | **16.900** | 4.73 |
| 4507 | | **21.20** | 0.0250 | 2.06 | 5700.0 | 10.5 | 30.17 | 19.75 | 1.53 | 0.70 | **21.199** | 5.13 |
| 3313 | ID08 | **18.30** | 0.0250 | 1.93 | 5000.0 | 9.4 | 25.61 | 18.04 | 1.42 | 0.71 | **18.300** | 4.87 |
| 4862 | | **29.90** | 0.0250 | 2.31 | 6500.0 | 13.3 | 41.47 | 23.67 | 1.75 | 0.72 | **29.900** | 5.78 |

**Note :-** Side slope of (V: H) 1:2 is taken, and Free board 0.5m is taken.

### Hydraulic Design Parameters of Collector Drains (CD)

| CH | Canal | Required Discharge | Roughness Coefficient | F.S.D | Bed Slope | Bed width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $m^3/s$ | | m | | m | $m^2$ | m | m | m/s | $m^3/s$ | |
| 0-683 | CD -1 | 9.400 | 0.0250 | 1.63 | 4500.0 | 6.3 | 14.21 | 12.15 | 1.17 | 0.66 | 9.400 | 3.86 |
| 683-1572 | | 9.520 | 0.0250 | 1.63 | 4500.0 | 6.3 | 14.35 | 12.22 | 1.17 | 0.66 | 9.520 | 3.87 |
| 0-522 | CD-2 | 11.80 | 0.0250 | 1.73 | 4500.0 | 7.2 | 16.96 | 13.45 | 1.26 | 0.70 | 11.800 | 4.18 |
| 522-1287 | | 11.86 | 0.0250 | 1.73 | 4500.0 | 7.2 | 17.03 | 13.48 | 1.26 | 0.70 | 11.864 | 4.18 |
| 1287-1528 | | 33.35 | 0.0250 | 2.38 | 6000.0 | 14.3 | 42.67 | 22.92 | 1.86 | 0.78 | 33.348 | 6.01 |
| 1528-2420 | | 33.51 | 0.0250 | 2.39 | 6000.0 | 14.4 | 42.83 | 22.97 | 1.86 | 0.78 | 33.509 | 6.02 |
| 2420-2708 | | 33.74 | 0.0250 | 2.41 | 6250.0 | 14.5 | 43.73 | 23.22 | 1.88 | 0.77 | 33.740 | 6.03 |
| 2708 - 4196 | | 33.84 | 0.0250 | 2.41 | 6250.0 | 14.6 | 43.83 | 23.25 | 1.88 | 0.77 | 33.838 | 6.04 |
| 4196 - 4242 | | 34.14 | 0.0250 | 2.42 | 6250.0 | 14.6 | 44.14 | 23.35 | 1.89 | 0.77 | 34.138 | 6.06 |
| 0-167 | CD-3 | 21.20 | 0.0250 | 2.16 | 6500.0 | 11.0 | 30.78 | 18.82 | 1.64 | 0.69 | 21.199 | 5.13 |
| 167 - 784 | | 21.30 | 0.0250 | 2.16 | 6500.0 | 11.1 | 30.89 | 18.86 | 1.64 | 0.69 | 21.296 | 5.13 |
| 784 - 1623 | | 21.48 | 0.0250 | 2.19 | 7000.0 | 11.3 | 31.98 | 19.20 | 1.67 | 0.67 | 21.484 | 5.15 |
| 0 - 509 | CD-4 | 1.68 | 0.0250 | 1.06 | 5500.0 | 2.2 | 4.07 | 6.07 | 0.67 | 0.41 | 1.680 | 2.11 |
| 509 - 1287 | | 1.83 | 0.0250 | 1.07 | 5000.0 | 2.3 | 4.19 | 6.17 | 0.68 | 0.44 | 1.828 | 2.17 |
| 1287 - 2065 | | 2.11 | 0.0250 | 1.11 | 5000.0 | 2.5 | 4.67 | 6.54 | 0.71 | 0.45 | 2.111 | 2.29 |
| 2065 - 2844 | | 2.33 | 0.0250 | 1.14 | 5000.0 | 2.7 | 5.03 | 6.81 | 0.74 | 0.46 | 2.325 | 2.36 |
| 2844 - 3464 | | 2.55 | 0.0250 | 1.17 | 5000.0 | 2.9 | 5.39 | 7.07 | 0.76 | 0.47 | 2.545 | 2.44 |
| 3464 - 3595 | | 2.86 | .0250 | 1.21 | 5000.0 | 3.1 | 5.89 | 7.42 | 0.79 | 0.48 | 2.856 | 2.54 |

**Note :-** Side slope of (V: H) 1:1.5 is taken, and Free board 0.5m is taken

### Hydraulic Design Parameters of Secondary Drains (SD)

| Reach | Canal | Required Discharge | Roughness Coefficient | F.S.D | F.B. | Bed Slope | Bed width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $m^3/s$ | | m | | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| 0-2248 | SD-1 | 0.299 | 0.0250 | 0.61 | 0.30 | 4000.0 | 0.70 | 0.98 | 2.89 | 0.34 | 0.31 | 0.299 | 1.15 | 302.39 |
| 2248-2576 | | 0.638 | 0.0250 | 0.81 | 0.40 | 5500.0 | 1.21 | 1.95 | 4.11 | 0.47 | 0.33 | 0.638 | 1.50 | 644.08 |
| 2576-2601 | | 0.693 | 0.0250 | 0.82 | 0.40 | 5500.0 | 1.28 | 2.07 | 4.25 | 0.49 | 0.33 | 0.692 | 1.55 | 700.12 |
| 0-2518 | SD-01-1(0) | 0.338 | 0.0250 | 0.63 | 0.30 | 4000 | 0.76 | 1.07 | 3.03 | 0.35 | 0.32 | 0.339 | 1.20 | 341.69 |
| 0-3877 | SD-01 -1 | 0.986 | 0.0250 | 0.86 | 0.40 | 4000.0 | 1.51 | 2.40 | 4.61 | 0.52 | 0.41 | 0.986 | 1.75 | 995.83 |
| 3877-3911 | | 1.679 | 0.0250 | 1.06 | 0.50 | 5500.0 | 2.24 | 4.06 | 6.06 | 0.67 | 0.41 | 1.679 | 2.11 | 1695.95 |
| 0-31 | SD-2 | 0.038 | 0.0250 | 0.20 | 0.30 | 750.0 | 0.25 | 0.11 | 0.97 | 0.11 | 0.34 | 0.038 | 1.00 | 37.93 |
| 31-865 | | 0.108 | 0.0250 | 0.31 | 0.30 | 750.0 | 0.31 | 0.24 | 1.43 | 0.17 | 0.45 | 0.108 | 1.00 | 109.08 |
| 865-1013 | | 0.163 | 0.0250 | 0.36 | 0.30 | 750.0 | 0.36 | 0.33 | 1.67 | 0.20 | 0.49 | 0.163 | 1.00 | 164.23 |
| 1013-1035 | | 0.231 | 0.0250 | 0.41 | 0.30 | 750.0 | 0.43 | 0.43 | 1.91 | 0.22 | 0.54 | 0.232 | 1.05 | 233.61 |

**Note :-** Side slope of (V: H) 1:1.5 is taken,

## Hydraulic Design Parameters of Tertiary Drains (TD)

| Reach | Canal | Required Discharge | Roughness Coefficient | F.S.D | Bed Slope | Bed width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $m^3/s$ | - | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| 0-790 | TD-1-1 | **0.046** | 0.0250 | 0.26 | 1000.0 | 0.26 | 0.14 | 1.00 | 0.14 | 0.34 | **0.046** | 1.00 | **46.32** |
| 790-1157 | | **0.060** | 0.0250 | 0.31 | 1500.0 | 0.31 | 0.19 | 1.19 | 0.16 | 0.31 | **0.060** | 1.00 | **60.43** |
| 1157-1875 | | **0.102** | 0.0250 | 0.38 | 1500.0 | 0.38 | 0.29 | 1.46 | 0.20 | 0.35 | **0.102** | 1.00 | **103.04** |
| 0-499 | TD-1-2 | **0.038** | 0.0250 | 0.24 | 1000.0 | 0.25 | 0.12 | 0.93 | 0.13 | 0.32 | **0.038** | 1.00 | **37.93** |
| 0- 806 | TD-1-3 | **0.059** | 0.0250 | 0.31 | 1600.0 | 0.31 | 0.20 | 1.21 | 0.16 | 0.30 | **0.059** | 1.00 | **60.00** |
| 806-1643 | | **0.094** | 0.0250 | 0.38 | 1800.0 | 0.38 | 0.29 | 1.47 | 0.20 | 0.32 | **0.094** | 1.00 | **94.65** |
| 1643-2593 | | **0.124** | 0.0250 | 0.43 | 2000.0 | 0.43 | 0.37 | 1.65 | 0.23 | 0.33 | **0.124** | 1.00 | **124.97** |
| 0-770 | TD-1-4 | **0.055** | 0.0250 | 0.30 | 1500.0 | 0.30 | 0.18 | 1.16 | 0.16 | 0.30 | **0.055** | 1.00 | **55.15** |
| 0-856 | TD-1-5 | **0.057** | 0.0250 | 0.31 | 1600.0 | 0.31 | 0.19 | 1.18 | 0.16 | 0.30 | **0.057** | 1.00 | **57.37** |
| 856-888 | | **0.088** | 0.0250 | 0.38 | 2000.0 | 0.38 | 0.29 | 1.46 | 0.20 | 0.31 | **0.089** | 1.00 | **88.91** |
| 880 | TD-1-6 | **0.031** | 0.0250 | 0.24 | 1600.0 | 0.25 | 0.12 | 0.94 | 0.13 | 0.25 | **0.031** | 1.00 | **31.30** |
| 590 | TD-2-1 | **0.044** | 0.0250 | 0.27 | 1200.0 | 0.27 | 0.14 | 1.02 | 0.14 | 0.31 | **0.044** | 1.00 | **44.33** |

| Reach | Canal | Required Discharge | Roughness Coefficient | F.S.D | Bed Slope | Bed width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $m^3/s$ | - | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| 971 | | **0.070** | 0.0250 | 0.33 | 1500.0 | 0.33 | 0.22 | 1.27 | 0.17 | 0.32 | **0.071** | 1.00 | **71.15** |
| 672 | TD-2-2 | **0.038** | 0.0250 | 0.24 | 1000.0 | 0.25 | 0.12 | 0.94 | 0.13 | 0.32 | **0.039** | 1.00 | **38.20** |
| 1108 | | **0.069** | 0.0250 | 0.33 | 1500.0 | 0.33 | 0.22 | 1.26 | 0.17 | 0.32 | **0.069** | 1.00 | **69.38** |
| 727 | TD-3-1 | **0.034** | 0.0250 | 0.23 | 1000.0 | 0.25 | 0.11 | 0.90 | 0.12 | 0.31 | **0.034** | 1.00 | **34.64** |
| 388 | TD-3-2 | **0.035** | 0.0250 | 0.23 | 1000.0 | 0.25 | 0.11 | 0.91 | 0.12 | 0.31 | **0.035** | 1.00 | **35.37** |
| 406 | TD-3-3 | **0.030** | 0.0250 | 0.21 | 1000.0 | 0.25 | 0.10 | 0.86 | 0.12 | 0.30 | **0.030** | 1.00 | **30.14** |
| 703 | TD-4-1 | **0.028** | 0.0250 | 0.21 | 1000.0 | 0.25 | 0.09 | 0.83 | 0.11 | 0.30 | **0.028** | 1.00 | **27.89** |
| 1510 | | **0.058** | 0.0250 | 0.30 | 1250.0 | 0.30 | 0.18 | 1.14 | 0.16 | 0.33 | **0.058** | 1.00 | **58.67** |
| 2501 | | **0.088** | 0.0250 | 0.36 | 1500.0 | 0.36 | 0.26 | 1.38 | 0.19 | 0.34 | **0.088** | 1.00 | **89.19** |
| 2821 | | **0.097** | 0.0250 | 0.37 | 1500.0 | 0.37 | 0.28 | 1.43 | 0.20 | 0.35 | **0.097** | 1.00 | **97.79** |
| 952 | TD-4-2 | **0.037** | 0.0250 | 0.25 | 1200. | 0.25 | 0.13 | 0.96 | 0.13 | 0.30 | **0.037** | 1.00 | **37.56** |

| Reach | Canal | Required Discharge | Roughness Coefficient | F.S.D | Bed Slope | Bed width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $m^3/s$ | - | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| | | | | | 0 | | | | | | | | |
| 1390 | | **0.059** | 0.0250 | 0.30 | 1350.0 | 0.30 | 0.18 | 1.16 | 0.16 | 0.32 | **0.059** | 1.00 | **59.58** |
| 801 | TD-4-3 | **0.055** | 0.0250 | 0.30 | 1300.0 | 0.30 | 0.17 | 1.13 | 0.15 | 0.32 | **0.056** | 1.00 | **56.03** |
| 1591 | | **0.114** | 0.0250 | 0.39 | 1300.0 | 0.39 | 0.30 | 1.48 | 0.20 | 0.38 | **0.114** | 1.00 | **115.59** |
| 1948 | | **0.146** | 0.0250 | 0.43 | 1400.0 | 0.43 | 0.37 | 1.64 | 0.22 | 0.39 | **0.146** | 1.00 | **147.12** |
| 2353 | | **0.175** | 0.0250 | 0.46 | 1400.0 | 0.46 | 0.42 | 1.76 | 0.24 | 0.41 | **0.176** | 1.00 | **177.12** |
| 2469 | | **0.187** | 0.0250 | 0.48 | 1500.0 | 0.48 | 0.46 | 1.83 | 0.25 | 0.41 | **0.188** | 1.00 | **189.12** |
| 16 | TD-4-4 | **0.022** | 0.0250 | 0.17 | 750.0 | 0.25 | 0.07 | 0.74 | 0.10 | 0.31 | **0.023** | 1.00 | **22.69** |
| 806 | | **0.082** | 0.0250 | 0.35 | 1500.0 | 0.35 | 0.25 | 1.34 | 0.18 | 0.33 | **0.082** | 1.00 | **82.69** |
| 1240 | | **0.113** | 0.0250 | 0.40 | 1500.0 | 0.40 | 0.31 | 1.51 | 0.21 | 0.36 | **0.113** | 1.00 | **113.80** |
| 897 | TD-4-5 | **0.063** | 0.0250 | 0.32 | 1500.0 | 0.32 | 0.20 | 1.21 | 0.17 | 0.31 | **0.063** | 1.00 | **63.27** |

| Reach | Canal | Required Discharge | Roughness Coefficient | F.S.D | Bed Slope | Bed width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $m^3/s$ | - | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| 1858 | | **0.122** | 0.0250 | 0.42 | 1750.0 | 0.42 | 0.35 | 1.60 | 0.22 | 0.35 | **0.122** | 1.00 | **122.78** |
| 1881 | | **0.161** | 0.0250 | 0.47 | 1750.0 | 0.47 | 0.43 | 1.78 | 0.24 | 0.37 | **0.162** | 1.00 | **163.06** |
| 721 | TD-4-6 | **0.043** | 0.0250 | 0.27 | 1250.0 | 0.27 | 0.14 | 1.02 | 0.14 | 0.30 | **0.043** | 1.00 | **43.68** |
| 1511 | | **0.103** | 0.0250 | 0.39 | 1750.0 | 0.39 | 0.31 | 1.50 | 0.21 | 0.33 | **0.103** | 1.00 | **103.68** |
| 1932 | | **0.132** | 0.0250 | 0.43 | 1750.0 | 0.43 | 0.37 | 1.66 | 0.23 | 0.35 | **0.133** | 1.00 | **133.76** |
| 728 | TD-4-7 | **0.068** | 0.0250 | 0.33 | 1700.0 | 0.33 | 0.22 | 1.28 | 0.17 | 0.30 | **0.068** | 1.00 | **68.49** |
| 749 | | **0.098** | 0.0250 | 0.40 | 2000.0 | 0.40 | 0.31 | 1.52 | 0.21 | 0.31 | **0.098** | 1.00 | **99.26** |
| 16 | TD-4-8 | **0.030** | 0.0250 | 0.21 | 1000.0 | 0.25 | 0.10 | 0.86 | 0.12 | 0.30 | **0.030** | 1.00 | **30.01** |
| 615 | | **0.064** | 0.0250 | 0.32 | 1500.0 | 0.32 | 0.20 | 1.22 | 0.17 | 0.31 | **0.063** | 1.00 | **64.19** |
| 1405 | | **0.123** | 0.0250 | 0.42 | 1750.0 | 0.42 | 0.36 | 1.61 | 0.22 | 0.35 | **0.124** | 1.00 | **124.19** |
| 1812 | | **0.152** | 0.0250 | 0.45 | 1750. | 0.45 | 0.41 | 1.74 | 0.24 | 0.37 | **0.151** | 1.00 | **153.23** |

| Reach | Canal | Required Discharge | Roughness Coefficient | F.S.D | Bed Slope | Bed width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $m^3/s$ | - | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| | | | | | 0 | | | | | | | | |
| 16 | TD-4-10 | **0.030** | 0.0250 | 0.22 | 1000.0 | 0.25 | 0.10 | 0.86 | 0.12 | 0.30 | **0.030** | 1.00 | **30.00** |
| 895 | | **0.084** | 0.0250 | 0.37 | 1750.0 | 0.37 | 0.27 | 1.40 | 0.19 | 0.32 | **0.084** | 1.00 | **85.19** |
| 1848 | | **0.144** | 0.0250 | 0.46 | 2000.0 | 0.46 | 0.42 | 1.75 | 0.24 | 0.34 | **0.144** | 1.00 | **145.19** |
| 17 | TD-4-11 | **0.015** | 0.0250 | 0.30 | 1600.0 | 0.30 | 0.18 | 1.16 | 0.16 | 0.29 | **0.053** | 1.00 | **15.54** |
| 1202 | | **0.063** | 0.0250 | 0.43 | 1600.0 | 0.43 | 0.37 | 1.65 | 0.22 | 0.37 | **0.136** | 1.00 | **63.43** |
| 2353 | | **0.093** | 0.0250 | 0.54 | 1600.0 | 0.54 | 0.59 | 2.08 | 0.28 | 0.43 | **0.255** | 1.00 | **93.57** |
| 2608 | | **0.236** | 0.0250 | 0.54 | 1600.0 | 0.58 | 0.61 | 2.11 | 0.29 | 0.44 | **0.266** | 1.06 | **238.76** |
| 2632 | | **0.263** | 0.0250 | 0.54 | 1600.0 | 0.60 | 0.62 | 2.14 | 0.29 | 0.44 | **0.272** | 1.10 | **265.24** |
| 806 | TD-5-1 | **0.022** | 0.0250 | 0.17 | 750.0 | 0.25 | 0.07 | 0.73 | 0.10 | 0.31 | **0.022** | 1.00 | **22.54** |
| 1402 | | **0.051** | 0.0250 | 0.29 | 1300.0 | 0.29 | 0.16 | 1.09 | 0.15 | 0.31 | **0.051** | 1.00 | **51.41** |

| Reach | Canal | Required Discharge | Roughness Coefficient | F.S.D | Bed Slope | Bed width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $m^3/s$ | - | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| 847 | TD-5-2 | **0.030** | 0.0250 | 0.21 | 1000.0 | 0.25 | 0.10 | 0.85 | 0.12 | 0.30 | **0.030** | 1.00 | **30.06** |
| 1160 | | **0.040** | 0.0250 | 0.26 | 1200.0 | 0.26 | 0.13 | 0.99 | 0.13 | 0.30 | **0.040** | 1.00 | **40.60** |
| 806 | TD-5-3 | **0.059** | 0.0250 | 0.31 | 1500.0 | 0.31 | 0.19 | 1.19 | 0.16 | 0.31 | **0.060** | 1.00 | **60.00** |
| 1217 | | **0.096** | 0.0250 | 0.37 | 1500.0 | 0.37 | 0.28 | 1.42 | 0.19 | 0.35 | **0.096** | 1.00 | **96.84** |
| 16 | TD-5-4 | **0.015** | 0.0250 | 0.13 | 500.0 | 0.25 | 0.05 | 0.61 | 0.08 | 0.33 | **0.016** | 1.00 | **15.53** |
| 870 | | **0.083** | 0.0250 | 0.35 | 1500.0 | 0.35 | 0.25 | 1.35 | 0.18 | 0.33 | **0.084** | 1.00 | **84.28** |
| 790 | TD-5-5 | **0.059** | 0.0250 | 0.31 | 1500.0 | 0.31 | 0.19 | 1.19 | 0.16 | 0.31 | **0.059** | 1.00 | **60.00** |
| 1032 | | **0.082** | 0.0250 | 0.36 | 1750.0 | 0.36 | 0.26 | 1.38 | 0.19 | 0.31 | **0.082** | 1.00 | **82.94** |
| 673 | TD-5-6 | **0.038** | 0.0250 | 0.26 | 1250.0 | 0.26 | 0.13 | 0.98 | 0.13 | 0.30 | **0.038** | 1.00 | **38.69** |
| 1212 | | **0.085** | 0.0250 | 0.36 | 1500.0 | 0.36 | 0.25 | 1.36 | 0.19 | 0.34 | **0.085** | 1.00 | **86.15** |
| 825 | TD-5-7 | **0.059** | 0.0250 | 0.31 | 1500.0 | 0.31 | 0.19 | 1.19 | 0.16 | 0.31 | **0.059** | 1.00 | **60.00** |

| Reach | Canal | Required Discharge | Roughness Coefficient | F.S.D | Bed Slope | Bed width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $m^3/s$ | - | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| 847 | | **0.068** | 0.0250 | 0.33 | 1500.0 | 0.33 | 0.22 | 1.26 | 0.17 | 0.32 | **0.069** | 1.00 | **69.05** |
| 16 | TD-5-8 | **0.022** | 0.0250 | 0.17 | 800.0 | 0.25 | 0.07 | 0.74 | 0.10 | 0.30 | **0.022** | 1.00 | **22.08** |
| 1089 | | **0.083** | 0.0250 | 0.36 | 1700.0 | 0.36 | 0.26 | 1.38 | 0.19 | 0.32 | **0.083** | 1.00 | **83.69** |
| 200 | TD-5-9 | **0.048** | 0.0250 | 0.28 | 1250.0 | 0.28 | 0.15 | 1.06 | 0.14 | 0.31 | **0.048** | 1.00 | **48.13** |
| 791 | TD-5-10 | **0.051** | 0.0250 | 0.27 | 1000.0 | 0.27 | 0.15 | 1.04 | 0.14 | 0.34 | **0.051** | 1.00 | **51.09** |
| 1131 | | **0.069** | 0.0250 | 0.33 | 1500.0 | 0.33 | 0.22 | 1.26 | 0.17 | 0.32 | **0.070** | 1.00 | **69.57** |
| 662 | TD-01-1(0) | **0.030** | 0.0250 | 0.20 | 750.0 | 0.25 | 0.09 | 0.81 | 0.11 | 0.33 | **0.030** | 1.00 | **29.86** |
| 1092 | TD-01-1(0)-1 | **0.055** | 0.0250 | 0.28 | 1000.0 | 0.28 | 0.16 | 1.07 | 0.15 | 0.35 | **0.055** | 1.00 | **55.25** |
| 1737 | TD-01-1(0)-2 | **0.121** | 0.0250 | 0.38 | 1000.0 | 0.38 | 0.28 | 1.44 | 0.20 | 0.43 | **0.120** | 1.00 | **122.18** |
| 2747 | TD-01-1-1 | **0.299** | 0.0250 | 0.51 | 1000.0 | 0.59 | 0.56 | 2.03 | 0.28 | 0.54 | **0.299** | 1.15 | **302.39** |
| 1155 | TD-01-1-1(0) | **0.074** | 0.0250 | 0.31 | 1000.0 | 0.31 | 0.20 | 1.20 | 0.16 | 0.38 | **0.074** | 1.00 | **75.15** |

| Reach | Canal | Required Discharge | Roughness Coefficient | F.S.D | Bed Slope | Bed width | Flow area | Wetted perimeter | Hydraulic radius | Flow velocity | Design Discharge | B/D | NIA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $m^3/s$ | - | m | 1m/m | m | $m^2$ | m | m | m/s | $m^3/s$ | - | ha |
| 1374 | TD-01-1-1(1) | **0.081** | 0.0250 | 0.37 | 2000.0 | 0.37 | 0.27 | 1.41 | 0.19 | 0.30 | **0.081** | 1.00 | **81.50** |
| 2962 | TD-01-1-2 | **0.114** | 0.0250 | 0.42 | 2000.0 | 0.42 | 0.35 | 1.61 | 0.22 | 0.33 | **0.115** | 1.00 | **115.01** |
| 2244 | TD-01-1-3 | **0.190** | 0.0250 | 0.51 | 1950.0 | 0.51 | 0.51 | 1.93 | 0.26 | 0.37 | **0.190** | 1.00 | **192.35** |
| 1729 | TD-01-1-3(0) | **0.082** | 0.0250 | 0.33 | 1000.0 | 0.33 | 0.21 | 1.24 | 0.17 | 0.39 | **0.082** | 1.00 | **83.25** |
| 1015 | TD-01-1-4 | **0.152** | 0.0250 | 0.49 | 2500.0 | 0.49 | 0.47 | 1.86 | 0.25 | 0.32 | **0.152** | 1.00 | **153.53** |
| 707 | TD-01-1-4(1) | **0.082** | 0.0250 | 0.37 | 2000.0 | 0.37 | 0.27 | 1.41 | 0.19 | 0.30 | **0.082** | 1.00 | **82.43** |
| 906 | TD-01-2-1 | **0.042** | 0.0250 | 0.26 | 1250.0 | 0.26 | 0.14 | 1.01 | 0.14 | 0.30 | **0.042** | 1.00 | **42.51** |
| 687 | TD-01-2-2 | **0.067** | 0.0250 | 0.29 | 750.0 | 0.29 | 0.16 | 1.10 | 0.15 | 0.41 | **0.068** | 1.00 | **67.97** |

**Note :-** Side slope of (V: H) 1:1 is taken, and Free board 0.2m is taken.