No.

The Republic of Malawi

Ministry of Irrigation and Water Development
Ministry of Agriculture and Food Security

THE STUDY ON THE CAPACITY DEVELOPMENT OF SMALLHOLDER FARMERS FOR THE MANAGEMENT OF SELF-HELP IRRIGATION SCHEMES (MEDIUM-SCALE) IN THE REPUBLIC OF MALAWI

FINAL REPORT

ANNEX 1

Technical Guidelines

August 2009

JAPAN INTERNATIONAL COOPERATION AGENCY
SANYU CONSULTANTS INC.

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ANNEX 1

Technical Guidelines
(Final Report)
For
The Management of Self-Help Irrigation Schemes (Medium-Scale)

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CHAPTER 1 INTRODUCTION

This Package aims to provide ultimate technical support and strength to the EPA / DAO Officers / farmers who are considered direct stakeholders in the rehabilitation of Smallholder Self-help Irrigation Schemes (Medium-Scale). The Package is prepared based on the outputs and lessons from the Verification Projects conducted at eight verification schemes as well as the discussions and results of DoI-DAES Workshops, ADD Workshops and farmer workshops.

The Package will intend to cover the technical fields of the following:

1) Rehabilitation of Irrigation Facilities,
2) Operation and Maintenance (O&M) of Irrigation Facilities,
3) Water Management of Irrigation Systems,
4) Farm Management and Agricultural Extension, and
5) Management of Farmers Group.

For the purpose of efficient dissemination and convenient use by different users, the Package is composed of the following:

a) Technical Guidelines for the use of the officers of the DoI/ADDs/DAOs/EPAs,
b) Technical Manuals for the use of the farmers,
c) Posters for general dissemination, and
d) Leaflet for general dissemination.

CHAPTER 2 REHABILITATION/CONSTRUCTION OF IRRIGATION FACILITIES

The guideline applies for rehabilitation and construction of medium scale irrigation facilities. It applies for simple and small scale structures which are made of stone masonry, brick masonry, stones, earth etc. However, it does not include construction of sophisticated structures e.g. reinforced concrete as well as use of heavy equipment. Most of the works under this guideline are to be done by the farmers manually. However, the guideline also contains other related detailed hydraulic analysis, structure analysis and stability analysis for structures.

2.1 River Diversion Weir

Diversion weir is a structure, which diverts water from a river into a canal for irrigation use. A fixed type weir is such a structure as to secure the required water level at intake, to avoid a considerable obstacle to floods and to have a section which is safe enough against external forces. In this project, fixed type weir is applied and its components are limited to main weir, apron, riverbed protection, riverbank protection etc. On the other hand; gate facility, control facility, sluice and fish ladder have not been included in the guideline.

(1) Rehabilitation / Construction Criteria

1) Material

Most of materials for rehabilitation work are procured locally whilst use of input from outside is minimized. Local materials include sand, stone, bricks, while cement, gabion, tools are regarded as outside materials. Local materials and outside materials are to be provided by the beneficiaries and donors respectively.

2) Labor

The rehabilitation work is done by the farmers under supervision of AEDO and IOs. Labor force is provided by the farmers group. Only transportation for materials (if necessary) is provided from outside.

(2) Investigation

Field investigations are carried out at and around the site as regards river conditions, effects on flood control and water use upstream and downstream, and foundation conditions. Prior to the investigations selecting necessary items for investigation, the appropriate investigation plan should be put in practice.

1) Investigation of river conditions

Investigation of river condition should be executed on (i) water level and discharge, (ii) sedimentation, (iii) stream centerline, (iv) riverbed slope, (v) riverbed materials.

(i) Water level and discharge

Highest water level and representative water level in each month are required to be obtained. Highest water level is obtained by observing past flood mark and by interviewing the villagers. Representative discharge in each month is estimated from water level, flow velocity and cross-section.

(ii) Sedimentation

River sediment is measured in order to arrange for sand removal plan. Sediment at a river structure of vicinity area can be referred.

(iii) Stream centerline

The location of the weir should be selected at a site where the stream centerline is stable and located near the riverbank where the intake is required.

(iv) Riverbed slope

Riverbed slope is an essential hydrological parameter and necessary to estimate discharge. Riverbed slope is obtained by surveying the elevation at 20m interval from 100m upstream to 100m downstream of the weir.

(v) Riverbed materials

Riverbed materials should be observed to estimate roughness coefficient. Value of roughness coefficient is shown in the **Table 2-1**.

Table 2-1 Roughness Coefficient of Natural Flow Canals

Materials and conditions of canals	Roughness Coefficient		
	Minimum	Standard	Maximum
Small canals on flat land			
1). Not weedy, straight. Neither cracks nor crevices are seen when water reaches the high water level	0.025	0.030	0.033
2) Weedy and stony. Neither cracks nor crevices are seen when water reaches the high water level	0.030	0.035	0.040
3) Not weedy but meandering. Some crevices and shallows are seen.	0.033	0.040	0.045
4) Some weeds and stones, meandering. Some abysses and shallows are seen.	0.035	0.045	0.050
5) Meandering. Some crevices and shallows are seen. The changes in gradients and cross-sections are few at low water level.	0.040	0.048	0.055
6) The same as 5) but stony.	0.045	0.050	0.060
7) Weeds and deep crevices are seen along moderate flow areas.	0.050	0.070	0.080
8) Area where weeds grow densely, deep crevices are seen, or many trees are present	0.075	0.100	0.115
Canals in mountain areas. No plants in canals. River banks are usually steep. Trees and shrubs along river banks are submerged when water reaches the high water level.			
1) Cobblestones and gravel on river bed	0.030	0.040	0.050
2) Large cobblestones on river bed	0.040	0.050	0.070
Large canals			
1) Constant cross sections without large cobblestones or shrubs	0.025		0.060
2) Rough and irregular cross sections	0.035		0.100

Source: Engineering Manual for Irrigation and Drainage Canal Works, The Japanese Institute of Irrigation and Drainage 1987.

2) Investigation on the influence of flood control and water use

The condition of drainage discharges into rivers upstream and downstream during the ordinary flow should be investigated in order to find the influence of rise of water level by weir upon drainability upstream and downstream. Flood water level and flood pond area should be investigated to decide the height of weir. Present condition of river utilization such as irrigation, hydropower, water rights, fishery and others should also be investigated.

3) Investigation on the foundations

Investigation on the foundations are executed for items such as the structure and properties of the ground, bearing capacity of the ground, conditions of riverbed deposits, ground water level and flow condition of ground water.

Investigation on the foundations should be carried out in order to design suitable foundation structures for the ground condition. Test pitting makes possible appraisal of strata and geology by the naked eye and to estimate bearing capacity. Standard allowable bearing capacity is shown in **Table 2-2**.

Table 2-2 Allowable Bearing Capacity of Foundation

Foundation		Allowable Bearing Capacity (kN/m^2)	Remarks		
			N-value	* qu (kN/m^2)	Friction Coefficient
Rock		1,000	~100		0.7
Solid Sand		500	~50		0.6
Semi consolidated silt, clay		300	~30		0.7
Conglomerate layer	Thick Not thick	600 300			0.6
Sand ground	Thick Medium thick Loose Very loose	300 { 200 100 50 0	30 – 50 { 20 – 30 10 – 20 5 – 10 ~5		0.6 0.5
Clayey ground	Very solid Solid Medium solid Soft Very soft	200 100 50 20 0	15 – 30 8 – 15 4 – 8 2 – 4 0 – 2	~250 100 – 250 50 – 100 25 – 50 ~25	0.5 0.45
Loam	Solid Rather solid Soft	150 100 50	~5 3 – 5 ~3	~150 100 – 150 ~100	

* Unconfined compression strength

Source: Technical Standard for River Works and Erosion and Sediment Control Works, Ministry of Land, Infrastructure and Transport, 1997

4) Investigation for construction works

Investigation for construction works should be conducted on the following items, which are necessary for construction planning.

(i) Meteorology, stream condition, ground water, riverbed conditions

Meteorology and stream condition should be thoroughly investigated because of their utmost importance for deciding the construction schedule based on the investigation on 10 year data of rainfall and river run off, channels, elevation of cofferdam, etc. Especially, temperature is important for work plan of concrete (mortar) works.

(ii) Construction equipment, tools, materials, transportation and labor.

Construction materials include cement, sand, gravel, stone, steel materials, bricks and timber etc. The supply situation of materials should be checked. Availability of local materials, necessity of transportation, availability of transportation and availability of tools should also be checked. Transportation of materials should be arranged if necessary. Minimum use of construction equipment is encouraged for medium scale irrigation schemes. Number of skilled labor and unskilled labor should also be checked.

5) Topographical survey

Topographical survey for weirs should be done on the following items;

(i) Plane survey

Plane survey is necessary not only for construction of the weir and intake but also for the planning and design of cofferdam. Curvature conditions of the river should be surveyed. It is desirable to draw contour lines on the map.

(ii) Longitudinal and cross section

Profile and cross section of the river are used for designing weir and hydraulic calculations.

(iii) Collection of topographic and other related maps

Prior to field investigations and surveys, topographic maps and other related maps around the scheme should be collected in order to prepare the investigation schedule, and to make a preliminary design.

6) Investigation for rehabilitation of existing facilities.

In case of rehabilitation of existing weir, following items should be investigated in addition to above items.

i) Present condition of existing weir

ii) Topographical survey for rehabilitation items

Table 2-3 List of Items to be Investigated (River Diversion Weir)

Items	Description	Method	Outputs
1. River Conditions			
(i) Water level and discharge	- Highest water level	- Observation of past flood mark and interview to the villagers	HWL=
	- Representative water level and flow velocity in each month	- Observation at the river	WL=
(ii) Sedimentation	- Sediment at a structure of vicinity area	- Observation of sediment configuration.	Stones, sand or silt
(iii) Stream centerline	- Stream centerline is stable.	- Visual observation at the river	Yes or no
	- Stream centerline is located near the bank where intake is required	- Visual observation at the river	Yes or no
(iv) Riverbed slope	- Riverbed slope	- Surveying. 20m interval, from 100m upstream to 100m downstream.	Riverbed slope=
(v) Riverbed materials	- Materials and conditions of the river	- Visual observation at the river	Estimated roughness coefficient=
2. Influence of flood control and water use			
(i) Drainage discharge into the river	- Influence to the drain	- Surveying location and elevation of drain	Location=, Elevation= No influence
(ii) Flood pond area	- Flood pond area does not influence farmland, trees etc.	- Observation at the site	No influence
	- Flood water level does not exceed river bank.	- Observation at the site	No influence
(iii) River utilization	- Present utilization of the river	- Irrigation for downstream Fish pond, Others	Requirement= lit/s Requirement= lit/s
	- Water rights	-Interview to relevant party	Quantity = lit/s. Water fee= MK
3. Foundation			
(i) River bed	- Depth of bedrock, allowable bearing capacity	- Visual observation, Test pitting, visual observation Penetration test	Outcrop, Depth of bedrock= Blow number at the depth=
(ii) Abutment	- Depth of bedrock, soil property	- Visual observation, test pitting	Outcrop, Depth of bedrock=, Soil property

	- Ground water	- Visual observation	Ground water level=
4. Construction works (i) Meteorology (ii) Construction equipment, materials, transportation	 - Collection of all existing meteorological data - Availability of materials - Number of available tools - Available transportation - Number of available labor	 - Data collection and site observation - Stone, Sand, Cement - Wheelbarrow, Bucket, Shovel, Pickaxe, etc. - Truck, tractor, oxcart - Skilled labor, Unskilled labor	 Annual rainfall, Stream condition, temperature, water level, Height of cofferdam = km from the site, = to be procured in___ = units, = pcs DAO, DA, ADD, Farmers, = number
5. Topographical survey (i) Plane survey (ii) Longitudinal and cross section (iii) Collection of topographic and other related maps.	 - Configuration of the river, centerline of the weir, location of intake, cofferdam, stockyard etc. should be indicated. - Longitudinal section of the river. - Cross section of the river along the weir centerline. - Longitudinal section of the main canal from inflow point to intake structure. - Cross section of the main canal at the intake structure. - Available maps around the scheme	 - Site surveying with measuring tape and compass. Plane table. - Site surveying with measuring tape and level. - Site surveying with measuring tape and level. - ditto - ditto - Data collection	 Plan: scale 1/100 Longitudinal section: scale 1/50 Cross section: scale 1/50 Longitudinal section: scale 1/50 Cross section: scale 1/50 Various maps
6. Investigation for rehabilitation (i) Present condition of existing weir	 - Dimensions of the weir - Material of the structure - Condition of material - Crack at the weir - Water leakage - Damage of the structure - Stability - Sediment - Longitudinal section of the structures to be	 - Site investigation, observation, measuring tape. - ditto - ditto - ditto - ditto - ditto - ditto - ditto - ditto	 Length= m, Base width= m, Top width= m, Upstream slope= , Downstream slope= , Material is= Condition of material is good/bad Location, length and width of the crack= Location of water leakage. Quantity of water leakage= lit/min. Location, situation Stable/not stable Configuration and depth Longitudinal section: scale 1/200~1/500

(ii) Topographical survey for rehabilitation items	rehabilitated. - Cross section of the structures to be rehabilitated.	- Site surveying with measuring tape and compass.	Cross section: scale 1/50

(3) Rehabilitation / Construction Planning / Design

1) General Layout

River diversion work is comprised of main weir, intake, spillway, apron, riverbed protection and slope protection.

The location of the weir should be decided considering stability of structure, operation and maintenance, canal slope, canal length and elevation of beneficiary area. Intake floor must be higher than the highest elevation of beneficiary area. The shorter length of canal is economical.

The elevation of both side banks should be high enough to avoid flooding upstream. If the elevation of the bank is not high enough, may result into a flood upstream by rising water level by the weir. The height of the weir should be decided considering flood water level of upstream. General layout of gravity diversion weir type irrigation scheme is shown in **Figure 2-1**.

Many of existing medium scale weir do not have apron, riverbed protection and slope protection. It is desirable to improve those parts. However, necessity of such improvement should be decided considering current situation of upstream and downstream riverbed and river bank.

Raising the crest of existing weir should be decided very carefully considering flood elevation and influence to riverbed, abutment and river bank.

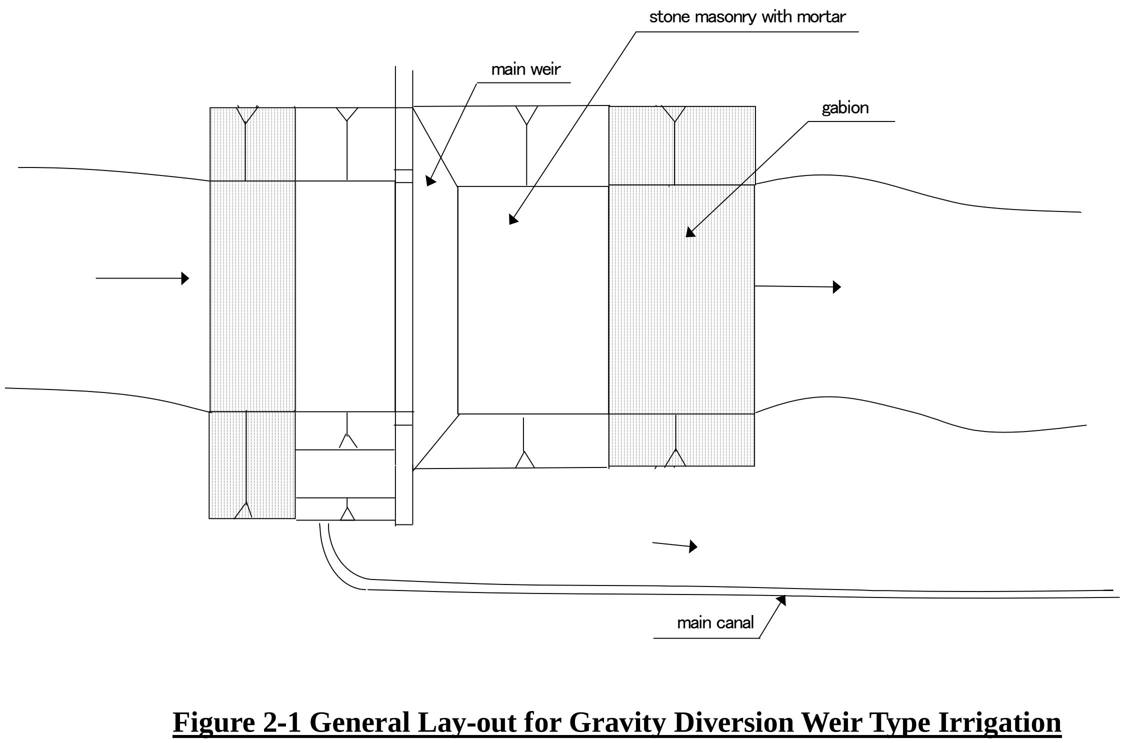


Figure 2-1 General Lay-out for Gravity Diversion Weir Type Irrigation

2) Design intake discharge and design intake water level

Design intake discharge should be the maximum intake discharge of the main canal at intake point. Design intake water level should be the water level of maximum intake discharge of the main canal at intake point.

3) Design flood discharge and design flood water level

a. Design flood discharge

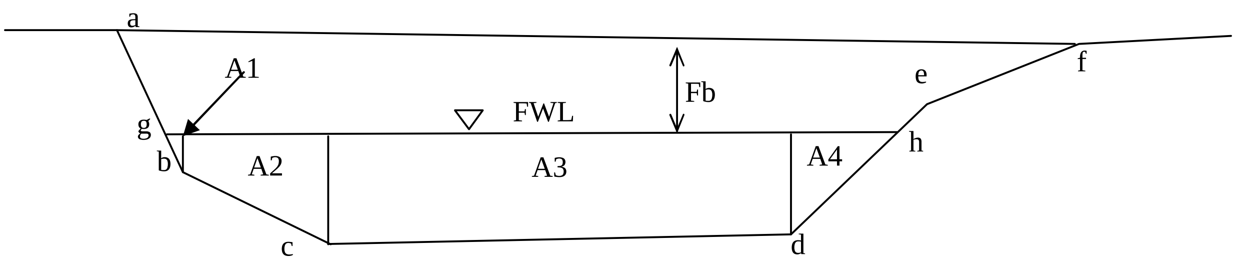


Figure 2-2 Sample Cross Section of a River

Design flood discharge should be the larger value of maximum experienced flood discharge or regional maximum flood discharge. Maximum experienced flood discharge is roughly estimated by Manning Formula. Required data and information are cross section of the river (refer to **Figure 2-2**), gradient, past maximum flood mark (elevation) and roughness coefficient.

$Q = A \times V$ (m^3/sec)
Where;
Q = Discharge (m^3/sec)
A = Flow area (m^2)
V = Flow velocity (m/sec)
$V = 1/n \times R^{2/3} \times I^{1/2}$
n = Roughness coefficient refer to **Table 2-1**
I = Gradient of the riverbed
R = Hydraulic mean depth (m)

Example
Coordinates; a(ax, ay), b(bx, by), c(cx, cy), d(dx, dy), e(ex, ey), f(fx, fy)
FWL; h (from past maximum flood mark)
gx = ax + (bx – ax) x (ay – h) / (ay – by), gy = h
hx = dx + (ex – dx) x (h – dy) / (ey – dy), hy = h
A = A1 + A2 + A3 + A4
A1 = (bx –gx) x (gy – by) / 2
A2 = ((h – by) + (h – cy)) x (cx – bx) / 2
A3 = ((h – cy) + (h – dy)) x (dx – cx) / 2
A4 = (hx – dx) x (h – dy) / 2
R = A / P P: Wetted Perimeter
P = gb + bc + cd + dh
$= \sqrt{((bx-gx)^2 + (h-by)^2)} + \sqrt{((cx-bx)^2 + (by-cy)^2)} + \sqrt{((dx-cx)^2 + (dy-cy)^2)}$
$+ \sqrt{((hx-dx)^2 + (h-dy)^2)}$

Table 2-4 shows referential hydraulic analysis result of uniform flow for simple shape river.

Regional maximum flood discharge is computed from specific discharge of maximum flood discharge of another dam in neighboring districts.

$Q = A \times q$
Q = Discharge (m^3/sec)
A = Catchment area (km^2)
q = Specific discharge (m^3/sec/km^2)

b. Design flood water level

Design flood water level should be lower than embankment. In this guideline, difference between design flood water level and top of riverbank (Fb in **Figure 2-2**) should be more than 0.6m. If Fb is less than 0.6m, a weir should not be constructed at the location. The weir should be designed so as to have Fb more than 0.6m.

Upstream depth of the river after construction of a weir is computed with various hydraulic analyses. However, in this guideline, simplified calculations, Manning Formula should be adopted. Calculation method is the same as that of design flood discharge explained in “a. Design flood discharge”. Cross section for calculation should be at the weir. Riverbed should assume as weir crest considering accumulation of sediment. Water flow area for calculation should be area (j, k, l, e, m) in **Figure 2.3**.

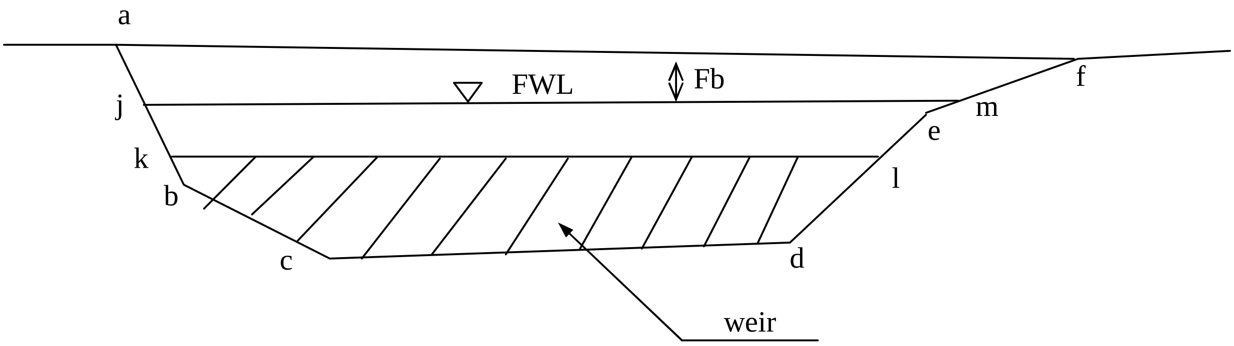


Figure 2-3 Sample Cross Section of a Weir

In case of perfect overflow at the weir, upstream depth of the weir at the design flood discharge is roughly estimated as below.

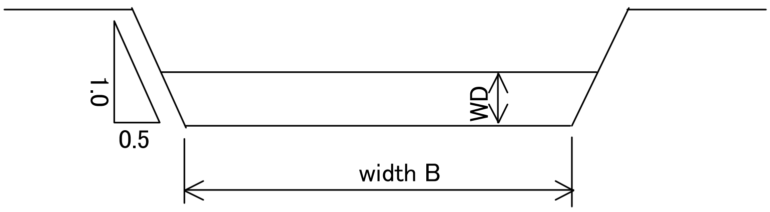
$qw = mo \times bw \times \sqrt{(2g)} \times h1^{3/2} = ko \times bw \times h1^{3/2}$ (m^3/sec)
qw = Discharge (m^3/sec)
mo, ko = Discharge coefficient, mo = 0.385, ko = 1.70 (considering a situation with sedimentation expected to accumulate on the top of the weir)
bw = Weir length (m)
g = Gravity acceleration (9.8m/sec^2)
h1 = Upstream head from the top of the weir (m)
$h1 = d1 + V^2 / 2g$
V = qw / A = qw / (d1 x bw)
d1 = Upstream depth

Source: Engineering Manual for Irrigation and Drainage Head Works, The Japanese Institute of Irrigation and Drainage 1989.

Table 2-5 shows referential hydraulic analysis result of perfect overflow at a weir.

Table 2-4 Referential Hydraulic Analysis Results of Uniform Flow

Assumed Cross Section of River



Roughness coefficient n = 0.045

Table Depth – Discharge B = 5.0m

Water Depth WD (m)	Gradient I	Velocity V (m/s)	Discharge (m^3/s)	Froude Number
1.000	0.010	1.851	10.179	0.591
1.200	0.010	2.032	13.658	0.593
1.400	0.010	2.195	17.514	0.593
1.600	0.010	2.342	21.733	0.591
1.800	0.010	2.477	26.305	0.590
2.000	0.010	2.602	31.222	0.588
2.200	0.010	2.718	36.480	0.585
2.400	0.010	2.828	42.076	0.583
2.600	0.010	2.931	48.009	0.581
2.800	0.010	3.029	54.279	0.578
1.000	0.005	1.309	7.198	0.418
1.200	0.005	1.437	9.657	0.419
1.400	0.005	1.552	12.384	0.419
1.600	0.005	1.656	15.368	0.418
1.800	0.005	1.751	18.600	0.417
2.000	0.005	1.840	22.077	0.416
2.200	0.005	1.922	25.795	0.414
2.400	0.005	2.000	29.752	0.412
2.600	0.005	2.073	33.948	0.411
2.800	0.005	2.142	38.381	0.409
1.000	0.003	1.069	5.877	0.341
1.200	0.003	1.173	7.885	0.342
1.400	0.003	1.267	10.112	0.342
1.600	0.003	1.352	12.548	0.341
1.800	0.003	1.430	15.187	0.340
2.000	0.003	1.502	18.026	0.339
2.200	0.003	1.569	21.062	0.338
2.400	0.003	1.633	24.293	0.337
2.600	0.003	1.692	27.718	0.335
2.800	0.003	1.749	31.338	0.334
1.000	0.002	0.828	4.552	0.264
1.200	0.002	0.909	6.108	0.265
1.400	0.002	0.982	7.832	0.265
1.600	0.002	1.047	9.719	0.264
1.800	0.002	1.108	11.764	0.264
2.000	0.002	1.164	13.963	0.263
2.200	0.002	1.216	16.314	0.262
2.400	0.002	1.265	18.817	0.261
2.600	0.002	1.311	21.470	0.260
2.800	0.002	1.355	24.274	0.259

Table Depth - Discharge B = 10.0m

Water Depth WD (m)	Gradient I	Velocity V (m/s)	Discharge (m^3/s)	Froude Number
1.000	0.010	2.007	21.071	0.641
1.200	0.010	2.227	28.321	0.649
1.400	0.010	2.426	36.346	0.655
1.600	0.010	2.610	45.097	0.659
1.800	0.010	2.780	54.536	0.662
2.000	0.010	2.938	64.635	0.664
2.200	0.010	3.086	75.370	0.665
2.400	0.010	3.226	86.720	0.665
2.600	0.010	3.358	98.670	0.665
2.800	0.010	3.484	111.206	0.665
1.000	0.005	1.419	14.899	0.453
1.200	0.005	1.574	20.026	0.459
1.400	0.005	1.716	25.700	0.463
1.600	0.005	1.845	31.888	0.466
1.800	0.005	1.966	38.563	0.468
2.000	0.005	2.078	45.704	0.469
2.200	0.005	2.182	53.295	0.470
2.400	0.005	2.281	61.320	0.470
2.600	0.005	2.375	69.770	0.471
2.800	0.005	2.464	78.634	0.470
1.000	0.003	1.159	12.165	0.370
1.200	0.003	1.286	16.351	0.375
1.400	0.003	1.401	20.984	0.378
1.600	0.003	1.507	26.037	0.381
1.800	0.003	1.605	31.487	0.382
2.000	0.003	1.696	37.317	0.383
2.200	0.003	1.782	43.515	0.384
2.400	0.003	1.863	50.068	0.384
2.600	0.003	1.939	56.967	0.384
2.800	0.003	2.011	64.205	0.384
1.000	0.002	0.897	9.423	0.287
1.200	0.002	0.996	12.666	0.290
1.400	0.002	1.085	16.254	0.293
1.600	0.002	1.167	20.168	0.295
1.800	0.002	1.243	24.389	0.296
2.000	0.002	1.314	28.906	0.297
2.200	0.002	1.380	33.706	0.297
2.400	0.002	1.443	38.782	0.298
2.600	0.002	1.502	44.126	0.298
2.800	0.002	1.558	49.733	0.297

Table Depth - Discharge B = 15.0m

Water Depth WD (m)	Gradient I	Velocity V (m/s)	Discharge (m^3/s)	Froude Number
1.000	0.010	2.070	32.091	0.661
1.200	0.010	2.308	43.210	0.673
1.400	0.010	2.527	55.534	0.682
1.600	0.010	2.729	68.985	0.689
1.800	0.010	2.918	83.500	0.695
2.000	0.010	3.095	99.029	0.699
2.200	0.010	3.262	115.527	0.703
2.400	0.010	3.420	132.960	0.705
2.600	0.010	3.570	151.294	0.707
2.800	0.010	3.713	170.504	0.709
1.000	0.005	1.464	22.692	0.468
1.200	0.005	1.632	30.554	0.476
1.400	0.005	1.787	39.269	0.482
1.600	0.005	1.930	48.780	0.487
1.800	0.005	2.063	59.044	0.491
2.000	0.005	2.188	70.024	0.494
2.200	0.005	2.306	81.690	0.497
2.400	0.005	2.418	94.017	0.499
2.600	0.005	2.524	106.981	0.500
2.800	0.005	2.626	120.565	0.501
1.000	0.003	1.195	18.528	0.382
1.200	0.003	1.333	24.948	0.389
1.400	0.003	1.459	32.063	0.394
1.600	0.003	1.576	39.829	0.398
1.800	0.003	1.684	48.209	0.401
2.000	0.003	1.787	57.174	0.404
2.200	0.003	1.883	66.700	0.406
2.400	0.003	1.974	76.764	0.407
2.600	0.003	2.061	87.350	0.408
2.800	0.003	2.144	98.441	0.409
1.000	0.002	0.926	14.352	0.296
1.200	0.002	1.032	19.324	0.301
1.400	0.002	1.130	24.836	0.305
1.600	0.002	1.220	30.851	0.308
1.800	0.002	1.305	37.343	0.311
2.000	0.002	1.384	44.287	0.313
2.200	0.002	1.459	51.665	0.314
2.400	0.002	1.529	59.461	0.315
2.600	0.002	1.597	67.661	0.316
2.800	0.002	1.661	76.252	0.317

Table Depth - Discharge B = 20.0m

Water Depth WD (m)	Gradient I	Velocity V (m/s)	Discharge (m^3/s)	Froude Number
1.000	0.010	2.105	43.152	0.672
1.200	0.010	2.353	58.174	0.686
1.400	0.010	2.583	74.845	0.697
1.600	0.010	2.796	93.059	0.706
1.800	0.010	2.997	112.731	0.714
2.000	0.010	3.186	133.789	0.720
2.200	0.010	3.364	156.173	0.724
2.400	0.010	3.534	179.828	0.729
2.600	0.010	3.697	204.711	0.732
2.800	0.010	3.852	230.781	0.735
1.000	0.005	1.489	30.513	0.476
1.200	0.005	1.664	41.135	0.485
1.400	0.005	1.826	52.923	0.493
1.600	0.005	1.977	65.803	0.499
1.800	0.005	2.119	79.713	0.505
2.000	0.005	2.253	94.603	0.509
2.200	0.005	2.379	110.431	0.512
2.400	0.005	2.499	127.158	0.515
2.600	0.005	2.614	144.753	0.518
2.800	0.005	2.723	163.187	0.520
1.000	0.003	1.215	24.914	0.388
1.200	0.003	1.359	33.587	0.396
1.400	0.003	1.491	43.212	0.403
1.600	0.003	1.614	53.728	0.408
1.800	0.003	1.730	65.085	0.412
2.000	0.003	1.839	77.243	0.415
2.200	0.003	1.942	90.166	0.418
2.400	0.003	2.041	103.824	0.421
2.600	0.003	2.134	118.190	0.423
2.800	0.003	2.224	133.241	0.425
1.000	0.002	0.941	19.298	0.301
1.200	0.002	1.052	26.016	0.307
1.400	0.002	1.155	33.472	0.312
1.600	0.002	1.251	41.617	0.316
1.800	0.002	1.340	50.415	0.319
2.000	0.002	1.425	59.832	0.322
2.200	0.002	1.505	69.843	0.324
2.400	0.002	1.581	80.422	0.326
2.600	0.002	1.653	91.550	0.327
2.800	0.002	1.722	103.208	0.329

Table Depth - Discharge B = 25.0m

Water Depth WD (m)	Gradient I	Velocity V (m/s)	Discharge (m^3/s)	Froude Number
1.000	0.010	2.127	54.232	0.679
1.200	0.010	2.382	73.172	0.695
1.400	0.010	2.618	94.212	0.707
1.600	0.010	2.840	117.220	0.717
1.800	0.010	3.048	142.089	0.726
2.000	0.010	3.245	168.727	0.733
2.200	0.010	3.432	197.057	0.739
2.400	0.010	3.610	227.010	0.744
2.600	0.010	3.781	258.527	0.749
2.800	0.010	3.944	291.556	0.753
1.000	0.005	1.504	38.348	0.480
1.200	0.005	1.684	51.740	0.491
1.400	0.005	1.852	66.618	0.500
1.600	0.005	2.008	82.887	0.507
1.800	0.005	2.155	100.472	0.513
2.000	0.005	2.294	119.308	0.518
2.200	0.005	2.427	139.340	0.523
2.400	0.005	2.553	160.520	0.526
2.600	0.005	2.673	182.806	0.530
2.800	0.005	2.790	206.161	0.533
1.000	0.003	1.228	31.311	0.392
1.200	0.003	1.375	42.246	0.401
1.400	0.003	1.512	54.393	0.408
1.600	0.003	1.640	67.677	0.414
1.800	0.003	1.760	82.035	0.419
2.000	0.003	1.873	97.415	0.423
2.200	0.003	1.981	113.771	0.427
2.400	0.003	2.084	131.064	0.430
2.600	0.003	2.183	149.261	0.432
2.800	0.003	2.277	168.330	0.435
1.000	0.002	0.951	24.253	0.304
1.200	0.002	1.065	32.724	0.311
1.400	0.002	1.171	42.133	0.316
1.600	0.002	1.270	52.422	0.321
1.800	0.002	1.363	63.544	0.325
2.000	0.002	1.451	75.457	0.328
2.200	0.002	1.535	88.127	0.331
2.400	0.002	1.615	101.522	0.333
2.600	0.002	1.691	115.617	0.335
2.800	0.002	1.764	130.388	0.337

Table 2-5 Referential Hydraulic Analysis Results of Perfect Over-flow at a Weir

Perfect Overflow Depth at the Weir

Q	k0	bw	h1	A	V	d1
8.500	1.700	5.000	1.000	3.465	2.453	0.693
11.174	1.700	5.000	1.200	3.840	2.910	0.768
14.080	1.700	5.000	1.400	4.480	3.143	0.896
17.203	1.700	5.000	1.600	5.540	3.105	1.108
20.527	1.700	5.000	1.800	6.235	3.292	1.247
24.042	1.700	5.000	2.000	6.930	3.469	1.386
27.737	1.700	5.000	2.200	7.620	3.640	1.524
31.604	1.700	5.000	2.400	8.315	3.801	1.663
35.635	1.700	5.000	2.600	9.005	3.957	1.801
39.825	1.700	5.000	2.800	9.700	4.106	1.940
17.000	1.700	10.000	1.000	6.930	2.453	0.693
22.347	1.700	10.000	1.200	7.680	2.910	0.768
28.161	1.700	10.000	1.400	8.960	3.143	0.896
34.406	1.700	10.000	1.600	11.080	3.105	1.108
41.054	1.700	10.000	1.800	12.470	3.292	1.247
48.083	1.700	10.000	2.000	13.860	3.469	1.386
55.473	1.700	10.000	2.200	15.240	3.640	1.524
63.207	1.700	10.000	2.400	16.630	3.801	1.663
71.270	1.700	10.000	2.600	18.010	3.957	1.801
79.650	1.700	10.000	2.800	19.400	4.106	1.940
25.500	1.700	15.000	1.000	10.395	2.453	0.693
33.521	1.700	15.000	1.200	11.520	2.910	0.768
42.241	1.700	15.000	1.400	13.440	3.143	0.896
51.608	1.700	15.000	1.600	16.620	3.105	1.108
61.581	1.700	15.000	1.800	18.705	3.292	1.247
72.125	1.700	15.000	2.000	20.790	3.469	1.386
83.210	1.700	15.000	2.200	22.860	3.640	1.524
94.811	1.700	15.000	2.400	24.945	3.801	1.663
106.906	1.700	15.000	2.600	27.015	3.957	1.801
119.475	1.700	15.000	2.800	29.100	4.106	1.940
34.000	1.700	20.000	1.000	13.860	2.453	0.693
44.694	1.700	20.000	1.200	15.360	2.910	0.768
56.321	1.700	20.000	1.400	17.920	3.143	0.896
68.811	1.700	20.000	1.600	22.160	3.105	1.108
82.108	1.700	20.000	1.800	24.940	3.292	1.247
96.167	1.700	20.000	2.000	27.720	3.469	1.386
110.946	1.700	20.000	2.200	30.480	3.640	1.524
126.414	1.700	20.000	2.400	33.260	3.801	1.663
142.541	1.700	20.000	2.600	36.020	3.957	1.801
159.300	1.700	20.000	2.800	38.800	4.106	1.940
42.500	1.700	25.000	1.000	17.325	2.453	0.693
55.868	1.700	25.000	1.200	19.200	2.910	0.768
70.401	1.700	25.000	1.400	22.400	3.143	0.896
86.014	1.700	25.000	1.600	27.700	3.105	1.108
102.636	1.700	25.000	1.800	31.175	3.292	1.247
120.208	1.700	25.000	2.000	34.650	3.469	1.386
138.683	1.700	25.000	2.200	38.100	3.640	1.524
158.018	1.700	25.000	2.400	41.575	3.801	1.663
178.176	1.700	25.000	2.600	45.025	3.957	1.801
199.125	1.700	25.000	2.800	48.500	4.106	1.940

2) Main Weir

Main weir should be made of concrete or stone masonry with mortar. The foundation should have enough bearing capacity and be impervious. The sectional shape of main weir body is trapezoid, being vertical or close to vertical on the upstream face and with a gentle slope on the downstream face, giving some width on the weir crest. Where there is a flow of stones, it may be desirable to make the slope of the upstream face gentle and that on the downstream face steep as in case of debris so as to protect the weir body from damage due to falling stones. Weir should be laid on sound and stable foundation. Surface soil of riverbed such as silt or sand should be removed. Standard cross section of main weir is shown in the **Figure 2-4** and stability condition shown in **Figure 2-5**.

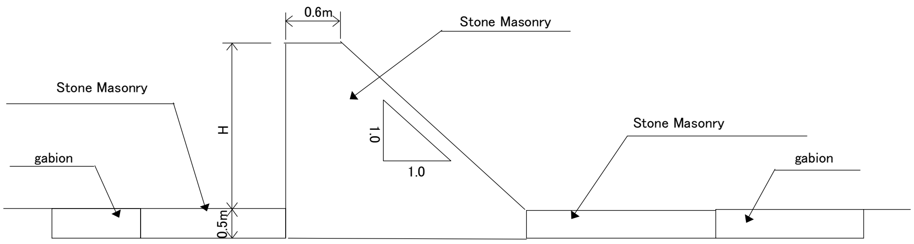


Figure 2-4 Standard Cross-Section of a Main Weir

a. Stability analysis

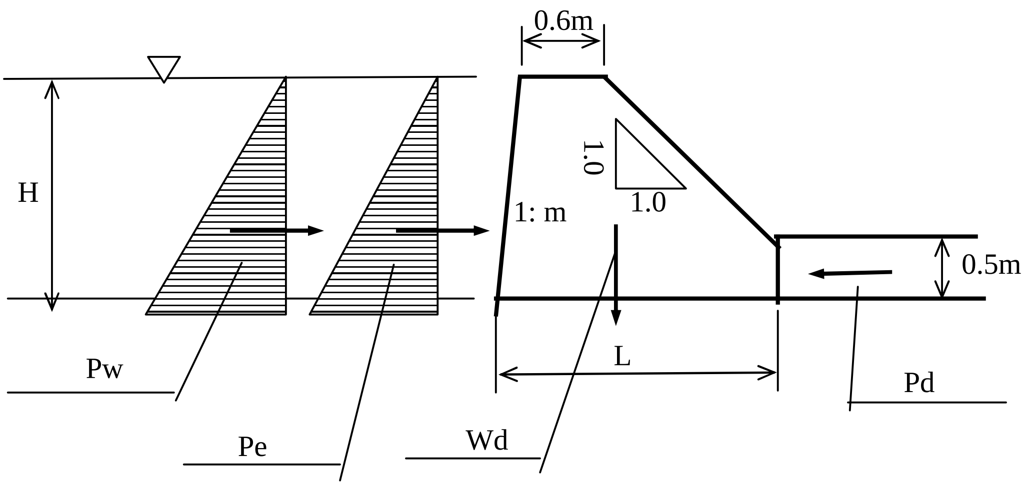


Figure 2-5 Stability Analysis Condition (Main Weir)

Pw: Hydrostatic pressure

$Pw = H^2 / 2$ (t)

Pe: Earth pressure due to sediment

$Pe = (w - wo) \times co \times H^2 / 2$ (t)

w: unit weight of deposited silt (1.8 t/m^3)

wo: unit weight of water (1.0 t/m^3)

co: coefficient of earth pressure co = 0.45

Pd: Downstream resisting pressure against sliding (in case of soil foundation)

$Pp = 0.5 \times La \times (2.3 - w0) \times \alpha$

La: length of apron (m)

α : coefficient of friction against ground (refer **Table 2-2**)

Wd: Dead weight of weir (t)

Condition of stability is;

(i) Safety against overturning

$e \leq l/6$

$e = |\Sigma M / \Sigma V - l/2|$

e: Eccentric distance (m)

ΣM : total of moments (t . m)

ΣV : resultant force of vertical force (t)

(ii) Safety against sliding

$Sf = \alpha \times \Sigma V / \Sigma H$

α : coefficient of friction against ground (refer **Table 2-2**)

Sf: safety factor Sf > 1.5

ΣH : resultant force of horizontal force (t)

(iii) Safety against settlement

The compressive strength at the bottom should be within the safe bearing capacity of the foundation.

$p = \Sigma V / A \times (1 \pm 6 \times e / l)$

p: compressive strength caused at both ends of the bottom (t/m^2)

A: bottom area (m^2)

Table 2-6 shows the result of sample stability analysis.

Case-1: Rock foundation, $\alpha = 0.7$, upstream slope: vertical, downstream slope 1:1.0, In case of weir height more than 4.0m, safety factor of sliding is less than 1.5. In this case, providing cut off is effective. There is no problem about safeness against overturning and safeness against settlement.

Case-2: Soil foundation, $\alpha = 0.45$, upstream slope: vertical, downstream slope 1:1.0, Even weir height is 1.0 m, safety factor of sliding is less than 1.5. In this case, providing the downstream stone masonry apron is effective.

Case-3: Soil foundation, $\alpha = 0.45$, upstream slope: vertical, downstream slope 1:1.0, with downstream sliding resistance force. In case that the weir height is more than 2.0m, required length of apron is very long.

Case-4: Soil foundation, $\alpha = 0.45$, upstream slope: 1:0.3, downstream slope 1:1.0, with downstream sliding resistance force. In case that the weir height is more than 3.0m, required length of apron is very long.

Case-5: Soil foundation $\alpha = 0.45$, upstream slope: 1:0.5, downstream slope 1:1.0, with downstream sliding resistance force. Making the upstream slope gentle, the length of apron can be reduced.

In all cases, the safety against overturning satisfies required condition. Maximum required compressive strength is about 10 t/ m^2 and it is smaller than allowable bearing capacity of solid clayey soil.

Table 2-6 Results of Sample Stability Analysis (Weir)

case-1 Stability Analysis of weir α=0.7, Foundation: Rock or semi consolidated clay

H	L	Pw	Pd	Pe	ΣV	ΣM	ΣH	e	l/6	Sf	p1	p2
m	m	t	t	t	t	t·m	t	m	m		t/m^2	t/m^2
1.0	1.100	0.500	0.000	0.180	2.243	1.350	0.680	0.052	0.183	2.308	2.616	1.461
1.5	1.600	1.125	0.000	0.405	4.370	3.724	1.530	0.052	0.267	1.999	3.266	2.196
2.0	2.100	2.000	0.000	0.720	7.073	7.816	2.720	0.055	0.350	1.820	3.899	2.837
2.5	2.600	3.125	0.000	1.125	10.350	14.083	4.250	0.061	0.433	1.705	4.538	3.423
3.0	3.100	4.500	0.000	1.620	14.203	22.983	6.120	0.068	0.517	1.624	5.186	3.976
3.5	3.600	6.125	0.000	2.205	18.630	34.972	8.330	0.077	0.600	1.566	5.841	4.509
4.0	4.100	8.000	0.000	2.880	23.633	50.509	10.880	0.087	0.683	1.520	6.500	5.028
4.5	4.600	10.125	0.000	3.645	29.210	70.051	13.770	0.098	0.767	1.485	7.163	5.537

case-2 Stability Analysis of weir α=0.45, Foundation: Solid Clayey Ground, without downstream horizontal force

H	L	Pw	Pd	Pe	ΣV	ΣM	ΣH	e	l/6	Sf	p1	p2
m	m	t	t	t	t	t·m	t	m	m		t/m^2	t/m^2
1.0	1.100	0.500	0.000	0.180	2.243	1.350	0.680	0.052	0.183	1.484	2.616	1.461
1.5	1.600	1.125	0.000	0.405	4.370	3.724	1.530	0.052	0.267	1.285	3.266	2.196
2.0	2.100	2.000	0.000	0.720	7.073	7.816	2.720	0.055	0.350	1.170	3.899	2.837
2.5	2.600	3.125	0.000	1.125	10.350	14.083	4.250	0.061	0.433	1.096	4.538	3.423
3.0	3.100	4.500	0.000	1.620	14.203	22.983	6.120	0.068	0.517	1.044	5.186	3.976
3.5	3.600	6.125	0.000	2.205	18.630	34.972	8.330	0.077	0.600	1.006	5.841	4.509
4.0	4.100	8.000	0.000	2.880	23.633	50.509	10.880	0.087	0.683	0.977	6.500	5.028
4.5	4.600	10.125	0.000	3.645	29.210	70.051	13.770	0.098	0.767	0.955	7.163	5.537

case-3 Stability Analysis of weir α=0.45, Foundation: Solid Clayey Ground, with downstream horizontal resisting force

H	L	Pw	Pd	Pe	ΣV	ΣM	ΣH	e	l/6	Sf	p1	p2	La
m	m	t	t	t	t	t·m	t	m	m		t/m^2	t/m^2	m
1.0	1.100	0.500	0.146	0.180	2.243	1.350	0.534	0.052	0.183	1.891	2.616	1.461	0.500
1.5	1.600	1.125	0.293	0.405	4.370	3.724	1.238	0.052	0.267	1.589	3.266	2.196	1.000
2.0	2.100	2.000	0.731	0.720	7.073	7.816	1.989	0.055	0.350	1.600	3.899	2.837	2.500
2.5	2.600	3.125	1.170	1.125	10.350	14.083	3.080	0.061	0.433	1.512	4.538	3.423	4.000
3.0	3.100	4.500	1.901	1.620	14.203	22.983	4.219	0.068	0.517	1.515	5.186	3.976	6.500
3.5	3.600	6.125	2.779	2.205	18.630	34.972	5.551	0.077	0.600	1.510	5.841	4.509	9.500
4.0	4.100	8.000	3.803	2.880	23.633	50.509	7.078	0.087	0.683	1.503	6.500	5.028	13.000
4.5	4.600	10.125	5.119	3.645	29.210	70.051	8.651	0.098	0.767	1.519	7.163	5.537	17.500

case-4 Stability Analysis of weir α=0.45, Foundation: Solid Clayey Ground, with downstream horizontal resisting force, upstream slope 1:0.3

H	L	Pw	Pd	Pe	ΣV	ΣM	ΣH	e	l/6	Sf	p1	p2	La
m	m	t	t	t	t	t·m	t	m	m		t/m^2	t/m^2	m
1.0	1.250	0.500	0.000	0.180	2.501	1.708	0.680	0.058	0.208	1.655	2.556	1.446	0.000
1.5	1.900	1.125	0.146	0.405	5.060	5.156	1.384	0.069	0.317	1.646	3.243	2.083	0.500
2.0	2.550	2.000	0.293	0.720	8.366	11.348	2.428	0.081	0.425	1.551	3.910	2.652	1.000
2.5	3.200	3.125	0.585	1.125	12.420	21.052	3.665	0.095	0.533	1.525	4.573	3.190	2.000
3.0	3.850	4.500	1.024	1.620	17.221	35.036	5.096	0.109	0.642	1.521	5.236	3.710	3.500
3.5	4.500	6.125	1.609	2.205	22.770	54.068	6.721	0.125	0.750	1.524	5.900	4.220	5.500
4.0	5.150	8.000	2.194	2.880	29.066	78.916	8.686	0.140	0.858	1.506	6.565	4.723	7.500
4.5	5.800	10.125	3.071	3.645	36.110	110.347	10.699	0.156	0.967	1.519	7.230	5.222	10.500

case-5 Stability Analysis of weir α=0.45, Foundation: Solid Clayey Ground, with downstream horizontal resisting force, upstream slope 1:0.5

H	L	Pw	Pd	Pe	ΣV	ΣM	ΣH	e	l/6	Sf	p1	p2	La
m	m	t	t	t	t	t·m	t	m	m		t/m^2	t/m^2	m
1.0	1.350	0.500	0.000	0.180	2.674	1.994	0.680	0.071	0.225	1.769	2.605	1.357	0.000
1.5	2.100	1.125	0.000	0.405	5.520	6.436	1.530	0.116	0.350	1.624	3.500	1.757	0.000
2.0	2.850	2.000	0.000	0.720	9.229	14.738	2.720	0.172	0.475	1.527	4.410	2.066	0.000
2.5	3.600	3.125	0.146	1.125	13.800	28.075	4.104	0.234	0.600	1.569	5.331	2.336	0.500
3.0	4.350	4.500	0.293	1.620	19.234	47.624	5.828	0.301	0.725	1.564	6.258	2.585	1.000
3.5	5.100	6.125	0.439	2.205	25.530	74.561	7.891	0.371	0.850	1.542	7.188	2.824	1.500
4.0	5.850	8.000	0.585	2.880	32.689	110.063	10.295	0.442	0.975	1.515	8.121	3.055	2.000
4.5	6.600	10.125	0.878	3.645	40.710	155.305	12.893	0.515	1.100	1.525	9.055	3.281	3.000

3) Apron

To prevent scouring downstream of the weir by the overflowing water, a downstream apron is provided. The length of the apron can be obtained from following formula. (Engineering Manual for Irrigation and Drainage Head Works, The Japanese Institute of Irrigation and Drainage 1989).

$L = 0.6 \times C \times \sqrt{H}$

Where, L: length of downstream apron (m)

C: Bligh's C, coefficient which varies depending on the type of the foundation. **(Table 2-7)**

H: Height of the weir from downstream riverbed (m)

Table 2-7 Coefficients for Blighs' Method and Lanes' Method

Foundation	Bligh's coefficient C	Lane's coefficient C'
Silty sand or silt	18	8.5
Fine sand	15	7.0
Medium sand	-	6.0
Coarse sand	12	5.0
Gravel	-	4.0
Coarse gravel	-	3.5
Sandy gravel	9	-
Cobble stone with gravel	-	3.0
Rocks with cobble stone and gravel	-	2.5
Rocks with gravel and sand	4 – 6	-
Soft clay	-	3.0
Medium clay	-	2.0
Heavy clay	-	1.8
Hard clay	-	1.6

Table 2-8 below contains computed lengths of aprons for different weir heights and soil conditions, with C for medium clay assumed at 5.0.

Table 2-8 Required Length of Apron

	Required length of apron (m)			
Height of weir (m)	Silty sand or silt	Fine sand	Coarse sand	Medium clay
1.0	7.7	6.4	5.1	2.2
1.5	10.8	9.0	7.2	3.0
2.0	13.3	11.1	8.9	3.7
2.5	15.3	12.8	10.2	4.3
3.0	17.1	14.3	11.4	4.8
3.5	18.8	15.6	12.5	5.2
4.0	20.3	16.9	13.5	5.7
4.5	21.6	18.0	13.4	6.0

4) Riverbed Protection and Slope Protection

Riverbed protection work is provided continuously to the apron to prevent scouring. Riverbed protection work prevent scour by reducing the energy of the high velocity flow that passes the weir gradually using the resistance of riverbed protection, making the flow velocity the same as that of downstream river following the riverbed protection.

The material of riverbed protection work should be gabions. Recommended length of riverbed protection work should be obtained from following Bligh's formula. Slope protection of both sides should be the same length and same material as apron and riverbed protection.

$La = L - Lb$

$L = 0.67 \times C \times \sqrt{\ } (H \times q) \times f$

La: Length of apron
Lb: length of riverbed protection (m)
L: total length of protection including length of apron la (m)
H: height of the weir from downstream riverbed.
q: flow quantity per unit width of design flood discharge (m^3/sec/m)
f: safety factor, 1.5 in case of movable weir, 1.0 in case of fixed weir
C: Bligh's coefficient
Generally, q = 2.0 to 8.0 in medium scale irrigation scheme.

From above 1) ~ 2), recommended dimensions of weir are shown in the **Table 2-9.**

Table 2-9 Standard Dimensions of Weir

a. Rock Foundation

Height of weir (m)	Upstream surface slope	Downstream surface slope	Length of apron (m)	Length of riverbed protection (m)	Remarks
1.0	Vertical	1:1.0	0	0	
1.5	Vertical	1:1.0	0	0	
2.0	Vertical	1:1.0	0	0	
2.5	Vertical	1:1.0	0	0	
3.0	Vertical	1:1.0	0	0	
3.5	Vertical	1:1.0	0	0	
4.0	Vertical	1:1.0	0	0	
4.5	Vertical	1:1.0	0	0	Provide cut off

b. Soil Foundation

Height of weir (m)	Upstream surface slope	Downstream surface slope	Length of apron , La (m)	Length of riverbed protection (m)	Remarks
1.0	Vertical	1:1.0	2.5	Lb	
1.5	Vertical	1:1.0	3.0	Lb	
2.0	Vertical	1:1.0	4.0	Lb	
2.5	1:0.3	1:1.0	4.5	Lb	
3.0	1:0.3	1:1.0	5.0	Lb	
3.5	1:0.3	1:1.0	5.5	Lb	
4.0	1:0.5	1:1.0	6.0	Lb	
4.5	1:0.5	1:1.0	6.0	Lb	

In case of rehabilitation of existing weir, the dimensions of the weir, apron and riverbed protection should be modified to meet above table.

5) Intake

The intake should function to make sure that intake design discharge from a river and transfer the flow to the irrigation canal. Generally discharges in rivers are subject to change and at the time of flood, huge amount of soil, sand and floating debris materials are carried by the river flow. Therefore, intake requires such as easy control of intake discharge and prevention of the materials carried from flowing into the canal. The intake is opened in the dry season and closed in the rainy season.

It is desirable to set the intake elevation higher than the riverbed elevation at least 0.5m to prevent soil and sand flowing into the canal.

The material of intake should be stone masonry. The sectional shape of intake body is trapezoid, being vertical on the upstream face and with a gentle slope on the downstream face. The crest elevation should be more than 0.6m higher than design flood water elevation. Pipes should also be installed at the elevation of 20cm from the canal bed. Upstream and downstream 1.0m, each section should be stone masonry lined to prevent scouring. Standard cross section of intake is shown in the **Figure 2-6** and stability Analysis condition is shown in **Figure 2-7**.

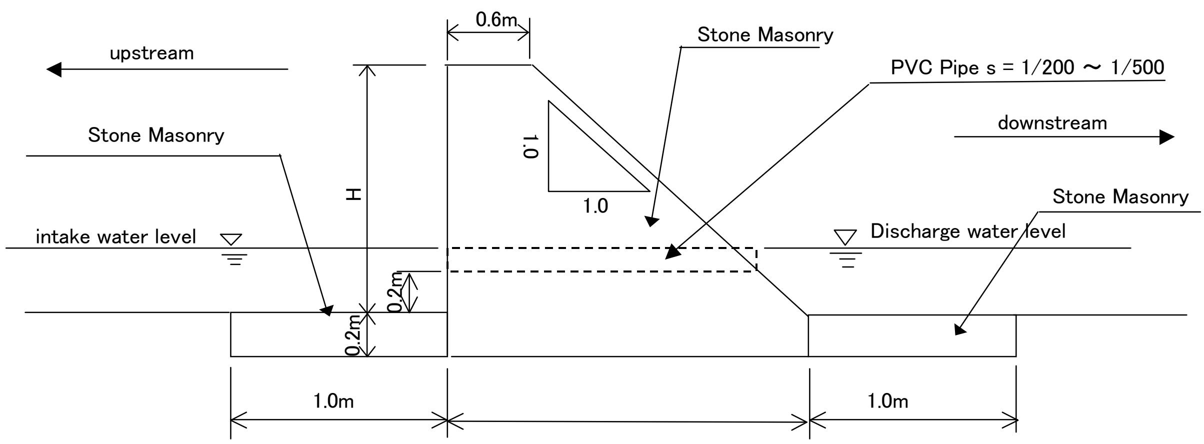


Figure 2-6 Standard Cross Section of Intake

a. Stability analysis

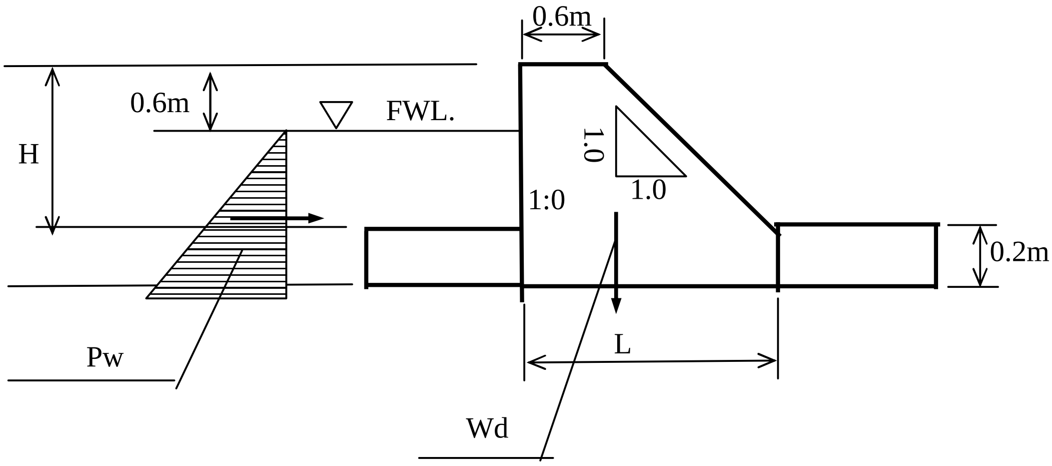


Figure 2-7 Stability Analysis Condition (Intake)

b. Capacity of pipe

Pipes are installed in the intake structure to convey water to canal. The water flow capacity of pipe is shown in the **Table 2-10** below;

Table 2-10 Maximum Pipe Flow Quantity of Uniform Flow

Pipe Diameter (Nom. Size)	Gradient 1/300	Gradient 1/500
ϕ 100	3.9 lit/s	3.1 lit/s
ϕ 125	6.7 lit/s	5.2 lit/s
ϕ 150	9.6 lit/s	7.5 lit/s
ϕ 200	24.4 lit/s	18.9 lit/s
ϕ 225	32.3 lit/s	25.1 lit/s
ϕ 450	177 lit/s	137 lit/s

In case of ϕ 140 and ϕ 200, it is recommended to install two pipes to control flow quantity. During wet season, pipes should be blocked with plastic paper or sacks.

Table 2-11 shows the result of stability analysis.

Case-1: Rock foundation, α = 0.7, upstream slope: vertical, downstream slope 1:1.0, Eccentric distance is less than l/6. Safety factor of sliding is more than 1.5. Maximum compressive strength is 5.9 t/ m^2.

Case-2: Soil foundation, α = 0.45, upstream slope: vertical, downstream slope 1:1.0, In case that the height is more than 4.3m, safety factor of sliding is less than 1.5. In this case, providing cut off is effective.

Table 2-11 Stability Analysis of Intake

case−1 Stability Analysis of intake α=0.7, Foundation: Rock or semi consolidated clay

H m	L m	Pw t	Pd t	Pe t	ΣV t	ΣM t·m	ΣH t	e m	l/6 m	Sf	p1 t/m^2	p2 t/m^2
1.0	1.600	0.180	0.000	0.000	2.208	2.112	0.180	0.157	0.267	8.587	2.190	0.570
1.5	2.100	0.605	0.000	0.000	4.106	4.703	0.605	0.096	0.350	4.750	2.489	1.421
2.0	2.600	1.280	0.000	0.000	6.578	8.892	1.280	0.052	0.433	3.597	2.832	2.228
2.5	3.100	2.205	0.000	0.000	9.626	15.091	2.205	0.018	0.517	3.056	3.212	2.998
3.0	3.600	3.380	0.000	0.000	13.248	23.712	3.380	0.010	0.600	2.744	3.618	3.742
3.5	4.100	4.805	0.000	0.000	17.446	35.168	4.805	0.034	0.683	2.541	4.043	4.467
4.0	4.600	6.480	0.000	0.000	22.218	49.872	6.480	0.055	0.767	2.400	4.481	5.179
4.5	5.100	8.405	0.000	0.000	27.566	68.236	8.405	0.075	0.850	2.296	4.931	5.879

case−2 Stability Analysis of intake α=0.45, Foundation: Solid Clayey Ground

H m	L m	Pw t	Pd t	Pe t	ΣV t	ΣM t·m	ΣH t	e m	l/6 m	Sf	p1 t/m^2	p2 t/m^2
1.0	1.600	0.180	0.000	0.000	2.208	2.112	0.180	0.157	0.267	5.520	2.190	0.570
1.5	2.100	0.605	0.000	0.000	4.106	4.703	0.605	0.096	0.350	3.054	2.489	1.421
2.0	2.600	1.280	0.000	0.000	6.578	8.892	1.280	0.052	0.433	2.313	2.832	2.228
2.5	3.100	2.205	0.000	0.000	9.626	15.091	2.205	0.018	0.517	1.964	3.212	2.998
3.0	3.600	3.380	0.000	0.000	13.248	23.712	3.380	0.010	0.600	1.764	3.618	3.742
3.5	4.100	4.805	0.000	0.000	17.446	35.168	4.805	0.034	0.683	1.634	4.043	4.467
4.0	4.600	6.480	0.000	0.000	22.218	49.872	6.480	0.055	0.767	1.543	4.481	5.179
4.3	4.900	7.605	0.000	0.000	25.358	60.425	7.605	0.067	0.817	1.500	4.750	5.600

6) Cutout

There are situations that a weir can be over flowed by surplus water even in the dry season. However, since most of weirs are used as a path to cross the river in the dry season, cutout is made to let surplus water to flow and so the top of the weir can be passed. The width of the top of the weir should be 0.6m. Arrangement of cut-out is shown in **Figure 2-8**, and the water flow capacity in **Table 2-12** below.

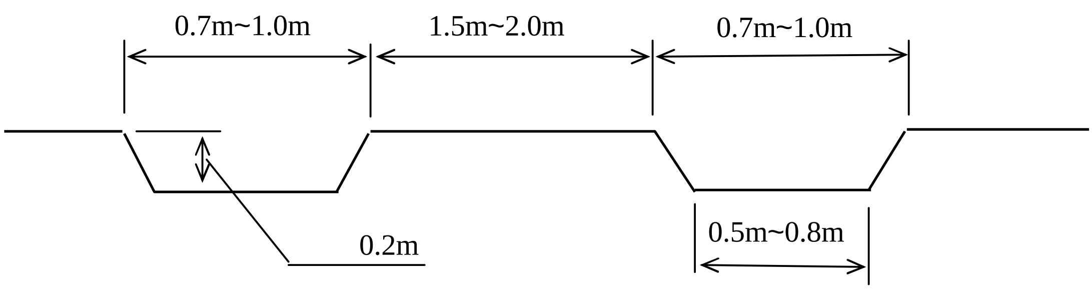


Figure 2-8 Cut-out Dimension Points of Weirs (Example)

Table 2-12 Water Flow Capacity of Cut-out

Bottom width (m)	Top width (m)	Depth (m)	Flow quantity (m^3/s)
0.5	0.7	0.2	0.15
0.6	0.8	0.2	0.18
0.7	0.9	0.2	0.21
0.8	1.0	0.2	0.24

(4) Rehabilitation plan

Rehabilitation plan should be made based on investigation result. From the investigation results, rehabilitation items are studied and rehabilitation work planned. Rehabilitation work should be planned to make the dam and facilities functional and safe to meet the condition and standard described in this guideline.

2.2 Water Impounding Dam

Water impounding dam is a structure in which water is saved by constructing a small dam/embankment at a stream. In Malawi, many of small-scale dam do not have an outlet and the farmers irrigate their farmland around the pond with watering can or treadle pump. This is also sometimes observed in Dimba farming, downstream of the pond. Only a few dam with outlet irrigate downstream area by gravity. Generally, available amount of water of the pond is limited and irrigable area should be decided carefully.

(1) Rehabilitation/Construction Criteria

Main items for rehabilitation and construction are embankment, spillway and outlet. Some dams have outlet and discharge pipes.

1) Material

Most of materials for the work should be procured locally and input from outside should be minimized. Locally available materials include; sand, stone, bricks, soil. Cement, gabion, tools are input from outside.

2) Labor

The work should be done by the farmers under supervision of AEDOs and IOs. Labor force is provided by the farmers association. Only transportation for materials (if necessary) might need assistance from outside.

(2) Investigation

Field investigations are carried out at and around the site on necessary items for design, construction, rehabilitation and O&M. Prior to the investigations selecting necessary items for investigation, the appropriate investigation plan should be put in practice.

1) Meteorological and hydrological investigations

Meteorological and hydrological conditions of the site should be investigated through data collection and observation. Items for meteorological and hydrological investigation include; temperature, precipitation, evaporation, wind direction, wind velocity and river discharge. These data are relevant in determination of dam scale, design flood discharge, design of dam body, outlet and intake facilities and formulation of construction planning.

2) Investigation of river conditions

This investigation is performed to clarify the present river conditions. Investigation items include discharge, water temperature, water quality, riverbed conditions etc. These data are the basis for investigation of the following items.

i) Volume and configuration of sediment (discharge and river bed conditions)
ii) Back water upstream of the pond and sediment (river bed conditions)
iii) Outlet type

3) Topographic investigations

Topography of the pond and surrounding area should be clarified through data collection and topographic survey. Topographic investigations are important to determine storage capacity and main features of the dam.

i) Pond and surroundings
Topographic survey covering an adequately wide area around the pond should be carried out for the determination of storage capacity, arrangement of dam related facilities, plan of access road and borrow area.
ii) Dam and surroundings
Topographic survey at the dam site should be executed in the required area with sufficient

accuracy to allow proper design of spillway, intake facilities and other appurtenant facilities, and also to calculate quantities of embanking, excavation and backfilling. This survey should also include longitudinal and cross sectional maps.

4) Geological investigation

Geological conditions of the pond and surrounding area including the dam site and borrow area also need to be clarified through data collection, field survey and observation.

i) Data collection and study
Existing data should be collected and studied. Necessary data and items to be studied are topographic map and aerial photographs, geological map, soil texture map and soil map.
ii) Surface geological survey
Data obtained through surface geological survey should include topography, geological structure, hydrogeology etc. Based on these data, possible landslide zones, existence of pervious foundation, distribution of materials and locations of fault and fractured zones are studied and the most adequate dam site is selected. Earth covering, soil properties, rock type, weathering conditions and depth of rocks can be estimated.
iii) Subsurface geological survey
This survey aims at classifying foundation ground at dam sites on the bases of engineering properties of the same such as geological conditions (lithologic character, fracture, etc.), physical, mechanical and hydraulic properties and presenting concrete data for determination of dam type and foundation improvement. In this medium scale irrigation project, since the height of water impounding dam is not high (generally less than 15m), subsurface geological survey are not be required.

5) Investigation for construction works

Investigation for construction works should be conducted on the following items, which are necessary for construction planning.

i) Meteorology, surface water, ground water, riverbed conditions
Meteorology and surface water should be thoroughly investigated because of their utmost importance for deciding the construction schedule. Based on the investigation on annual rainfall and river run off, channels, elevation of cofferdam, etc. should be determined. Especially, temperature is important for work plan of concrete (mortar) works. No concrete (mortar) should be mixed or placed when the shade air temperature reached thirty-five degrees centigrade (35°C) or more.
ii) Construction equipment and materials
Construction materials include cement, soil, sand, gravel, stone, steel materials, bricks and timber etc. The supply situation of materials should be checked. Availability of local materials, necessity of transportation, availability of transportation and availability of tools should be checked. Transportation of materials should be arranged if necessary. Minimum use of construction equipment is encouraged for medium scale irrigation schemes basically. Number of skilled labor and unskilled labor should be checked.

6) Investigation for Rehabilitation of Existing Dam

In case of rehabilitation of existing dam, following items should be investigated in addition to above items. (Refer to **Table 2-13**)

i) Present condition of existing dam
ii) Topographical survey for rehabilitation items
iii) Data on water use management of existing dam
iv) Operation and maintenance system of existing dam

Table 2-13 List of Items to be Investigated (Water Impounding Dam)

Items	Description	Method	Outputs
1. Meteorological and hydrological investigations	- Collection of meteorological and hydrological data	- Data collection and site observation	- Annual rainfall, temperature, wind direction, wind velocity, river discharge, evaporation, other dams' data
2. River conditions (i) Water level and discharge	- Highest water level - Representative water level and flow velocity in each month	- Observation of past flood mark and interview to the villagers - Observation at the river	HWL= WL=
(ii) Sedimentation	- Sediment at a structure of vicinity area	- Observation of sediment configuration.	Stones, sand or silt
(iii) Riverbed slope	- Riverbed slope	- Surveying. 20m interval, from 100m upstream to 100m downstream.	Riverbed slope =
(iv) Riverbed materials	- Materials and conditions of the river	- Visual observation at the river	Estimated roughness coefficient=
(v) River Utilisation	- Water rights	- Interview to relevant party	Quantity = lit/s Water fee = MK
3. Topographic investigations (i) Pond and surroundings	- Shape of the pond, centerline of the dam, location of spillway, intake, cofferdam, stockyard, contour line etc. should be indicated.	- Site surveying with measuring tape and compass. Plane table. Site surveying with measuring tape and level	Plan: scale 1/1000~1/2000
(ii) Dam and surroundings	- Longitudinal section of the dam center. - Cross section of the along dam centerline. - Longitudinal section of the spillway. - Cross section of the along the spillway centerline.	- Site surveying with measuring tape and level. ditto ditto ditto	- Longitudinal section: scale 1/200~1/500 Cross section: scale 1/50
(iii) Collection of topographic and other related maps.	- Available maps around the scheme	Data collection	Various maps
4. Geological investigation (i) Data collection	- Collection of existing geological data	- Data collection	- Topographic map, aerial photographs, geological map, soil texture, soil map
(ii) Surface geological survey	- Location of the dam, design conditions	- Site surveying	- Location of possible land slide zones, pervious foundation, fault,

			fractured zones. Distribution of materials, earth covering, soil properties, rock type, weathering conditions, depth of rocks
5. Construction works (i) Meteorology (ii) Construction equipment, materials, transportation	- Collection of all existing meteorological data - Availability of materials - Number of available tools - Available transportation - Number of available labor	- Data collection and site observation - Soil, Stones, Sand, Cement - Wheelbarrow, Bucket, Shovel, Pickaxe, Trowel, Others - Truck, tractor, oxcart - Skilled labor, Unskilled labor	Annual rainfall, Stream condition, temperature, water level Height of cofferdam = = km from the site, = to be procured in___ = units, = pcs, DAO, DA, ADD Farmers, = number
6. Rehabilitation of existing dam (i) Present condition of existing dam (ii) Topographical survey for rehabilitation items (iii) Data on water use management of existing dam (iv) Operation and maintenance system of existing dam	- Crack at embankment - Erosion of embankment - Collapse/deformation of embankment - Seepage at downstream - Damage of structures - Freeboard - Function, capacity of spillway - Function, capacity of intake - Sediment - Safety - Longitudinal section of the structures to be rehabilitated. - Cross section of the structures to be rehabilitated. - Discharge for outlet - Operation and maintenance	- Site investigation, observation, measuring tape. - ditto - ditto - ditto - ditto - ditto - ditto - ditto - ditto - ditto - Site surveying with measuring tape and compass. Plane table. - Daily operation record of outlet. -Operation and maintenance record	Length= m, width= cm Length= m, width= m Length= m, width= m Location, quantity= lit/min Location, situation Fb= m Enough or not Enough or not Configuration and depth Good or bad - Longitudinal section: scale 1/200~1/500 Cross section: scale 1/50 - Daily discharge for the canal. - Operation and maintenance record.

(3) Rehabilitation/Construction Planning/Design

1) General Layout

General layout of water impounding dam type irrigation scheme is shown in **Figure 2-9**.

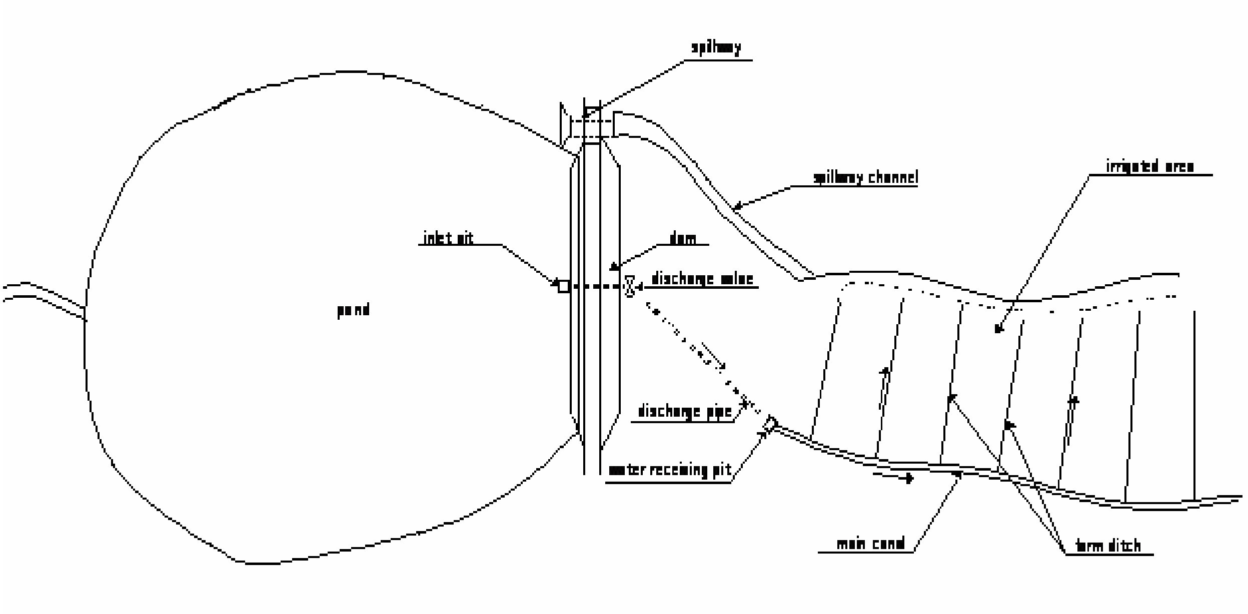


Figure 2-9 General Lay-out for Water Impounding Dam Type

2) Design flood discharge and design flood water level

a) Design flood discharge
Design flood discharge should be the maximum value of experienced flood discharge or regional maximum flood discharge.
Design flood discharge is estimated as same as 2.1 (3) 3) a.
b) Design flood water level
Design high water level at spillway.

3) Embankment

Embankment and foundation should have enough water tightness and strength, and be safe against sliding failure or seepage failure.

Standard cross section of the dam should be as follows;

Upstream Slope: 1:1.5 (in case that the dam height is less than 5.0m)
1:2.0 (in case that the dam height is more than 5.0m)
Downstream slope: 1:1.5 (in case that the dam height is less than 5.0m)
1:2.0 (in case that the dam height is more than 5.0m)
Crest width: minimum 3.0m
Crest elevation: 1.0m higher than flood water level
Berm: width 1.0m at every 5.0m height
Slope protection: vegetation

A standard Cross section of a dam is shown in **Figure 2-10.**

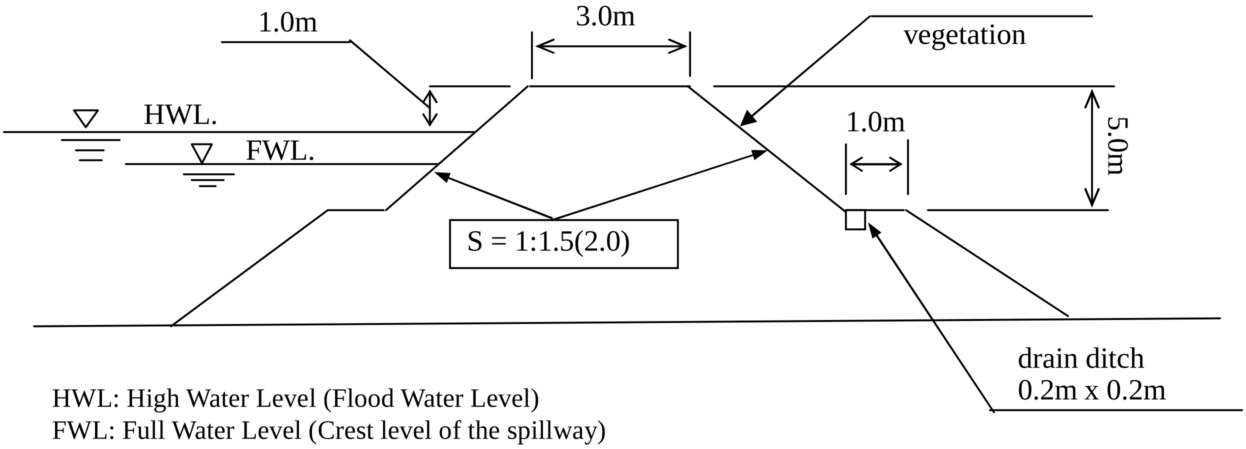


Figure 2-10 Standard Cross Section of a Dam

4) Spillway

The spillway structure should be designed to ensure the safe release of a maximum flow equivalent to the design flood discharge. The spillway structure must be carefully determined so as not to produce adverse effects on the dam body, foundation and reservoir.

The water velocity of spillway channel should be very high due to steep slope. Energy dissipation section should be set at the end of spillway channel connecting to existing river.

Concrete or stone masonry with mortar is preferable for the material for spillway due to its solidness and durability.

Freeboard of spillway downstream channel should be not less than 0.6m. Channel bed width should not be less than 1.0 m considering maintenance. In case of the wall height exceeds 1.0m, weep holes should be installed at the middle height of the wall and 1.5 m interval in the wall of downstream channel. Weep holes should be 50 mm diameter PVC pipe.

Figure 2-10 shows the general longitudinal section of a spillway. **Table 2-14~Table 2-18** show hydraulic analyses of Inlet Channel (both Open Canal and Pipe Culvert) and Spillway Channels.

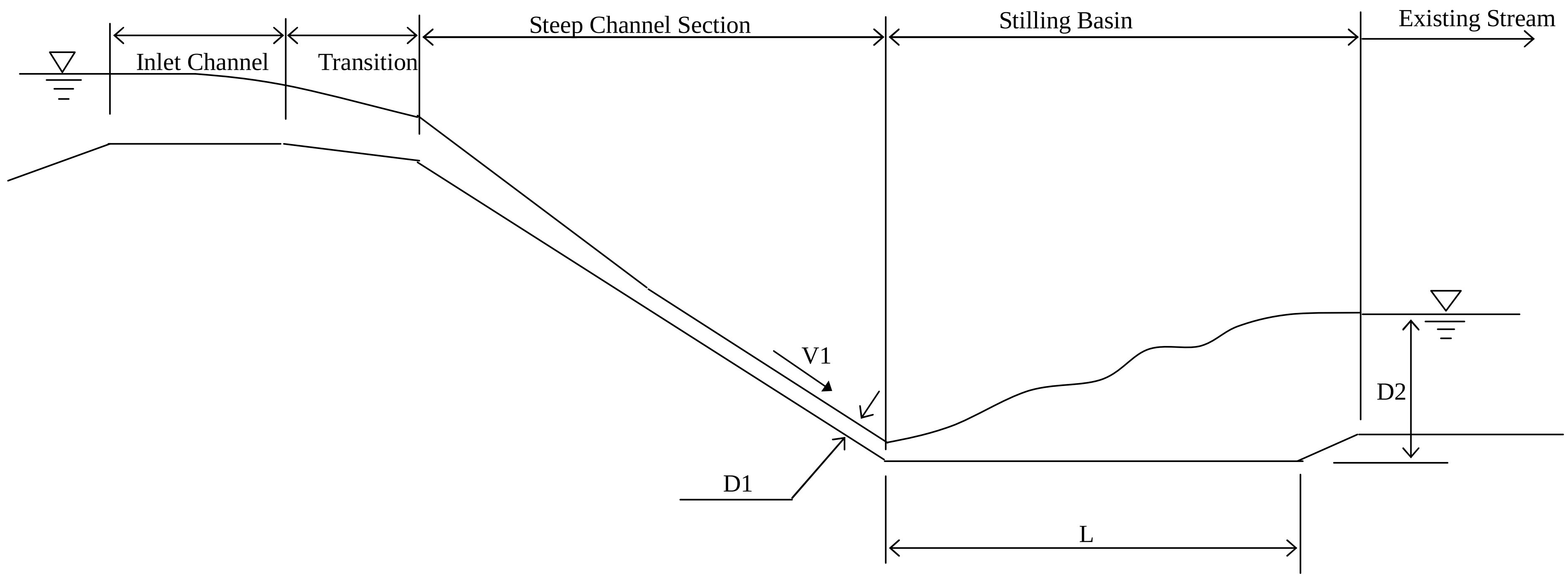
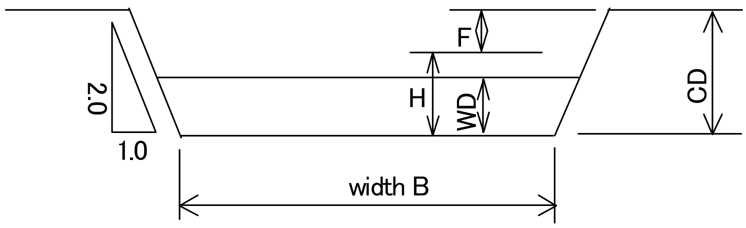


Figure 2-11 General Longitudinal Section of Spillway

Table 2-14 Head at Inlet Channel (Open Canal)

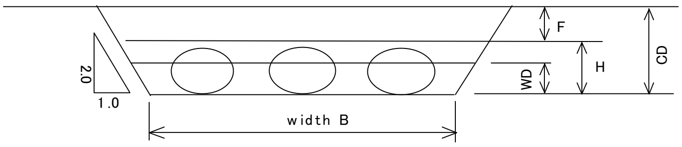


F > 1.0m

critical depth

Discharge (m^3/s)	Channel width B (m)	Water Depth WD (m)	Velocity V (m/s)	Head (m)	Freeboard F (m)	Channel Depth CD (m)
1.000	1.000	0.433	1.898	0.617	1.083	1.700
	1.500	0.343	1.745	0.498	1.002	1.500
	2.000	0.287	1.624	0.422	1.078	1.500
5.000	1.500	0.934	2.720	1.311	1.089	2.400
	2.000	0.802	2.596	1.146	1.054	2.200
	2.500	0.706	2.482	1.020	1.080	2.100
	3.000	0.633	2.380	0.922	1.078	2.000
	3.500	0.576	2.291	0.844	1.056	1.900
10.000	4.000	0.830	2.727	1.209	1.091	2.300
	5.000	0.724	2.577	1.063	1.037	2.100
	6.000	0.645	2.452	0.952	1.048	2.000
	7.000	0.584	2.347	0.865	1.035	1.900
	8.000	0.536	2.256	0.796	1.004	1.800
15.000	6.000	0.840	2.780	1.234	1.066	2.300
	7.000	0.762	2.665	1.124	1.076	2.200
	8.000	0.700	2.566	1.036	1.064	2.100
	9.000	0.649	2.479	0.963	1.037	2.000
	10.000	0.606	2.402	0.900	1.000	1.900
20.000	9.000	0.784	2.716	1.160	1.040	2.200
	10.000	0.733	2.633	1.087	1.013	2.100
	11.000	0.689	2.560	1.023	1.077	2.100
	12.000	0.651	2.493	0.968	1.032	2.000
	14.000	0.589	2.377	0.877	1.023	1.900
30.000	14.000	0.770	2.710	1.145	1.055	2.200
	16.000	0.705	2.601	1.050	1.050	2.100
	18.000	0.653	2.507	0.974	1.026	2.000
	20.000	0.609	2.425	0.909	1.091	2.000
	22.000	0.572	2.353	0.854	1.046	1.900
40.000	18.000	0.790	2.753	1.177	1.023	2.200
	20.000	0.737	2.664	1.099	1.001	2.100
	22.000	0.692	2.585	1.033	1.067	2.100
	24.000	0.654	2.515	0.977	1.023	2.000
	26.000	0.620	2.451	0.927	1.073	2.000
50.000	24.000	0.758	2.705	1.131	1.069	2.200
	26.000	0.719	2.637	1.074	1.026	2.100
	28.000	0.685	2.575	1.023	1.077	2.100
	30.000	0.654	2.519	0.978	1.022	2.000
	32.000	0.627	2.467	0.938	1.062	2.000

Table 2-15 Head at Inlet Channel (Pipe Culvert)



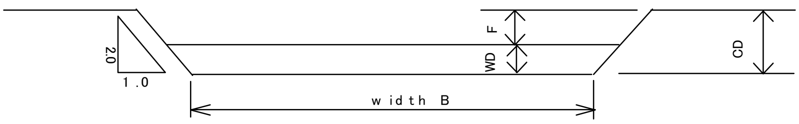
F > 1.0m

critical depth of pipe culvert

Discharge (m^3/s)/pipe	Diameter D (m)	Water Depth WD (m)	Velocity V (m/s)	Head H (m)	Freeboard F (m)	Channel Depth CD (m)
0.200	0.600	0.289	1.484	0.401	1.099	1.500
0.400	0.600	0.415	1.919	0.603	1.097	1.700
0.600	0.600	0.503	2.370	0.790	1.010	1.800
0.800	0.600	0.556	2.926	0.993	1.007	2.000
1.000	0.600	0.580	3.573	1.231	1.069	2.300
0.200	0.900	0.256	1.341	0.348	1.052	1.400
0.400	0.900	0.367	1.643	0.505	1.095	1.600
0.600	0.900	0.453	1.869	0.631	1.069	1.700
0.800	0.900	0.527	2.068	0.745	1.055	1.800
1.000	0.900	0.592	2.255	0.851	1.049	1.900
1.200	0.900	0.649	2.443	0.954	1.046	2.000
1.400	0.900	0.700	2.637	1.055	1.045	2.100

B = D x n + (n + 1.0) x 0.5 (m)
D: diameter of culvert
n: number of pipe culvert

Table 2-16 Critical Depth of Spillway Downstream Channel



F > 0.6m

critical depth

Discharge (m^3/s)	Channel width B (m)	Water Depth WD (m)	Velocity V (m/s)	Freeboard F (m)	Channel Depth CD (m)
1.000	1.000	0.433	1.898	0.667	1.100
	1.500	0.343	1.745	0.657	1.000
	2.000	0.287	1.624	0.613	0.900
5.000	1.000	1.124	2.847	0.676	1.800
	1.500	0.934	2.720	0.666	1.600
	2.000	0.802	2.596	0.698	1.500
	2.500	0.706	2.482	0.694	1.400
	3.000	0.633	2.380	0.667	1.300
10.000	1.000	1.646	3.333	0.654	2.300
	2.000	1.226	3.120	0.674	1.900
	3.000	0.985	2.908	0.615	1.600
	4.000	0.830	2.727	0.670	1.500
	5.000	0.724	2.577	0.676	1.400
15.000	2.000	1.561	3.456	0.639	2.200
	3.000	1.269	3.253	0.631	1.900
	4.000	1.076	3.071	0.624	1.700
	5.000	0.941	2.914	0.659	1.600
20.000	2.000	1.846	3.708	0.654	2.500
	3.000	1.515	3.515	0.685	2.200
	4.000	1.291	3.333	0.609	1.900
	5.000	1.132	3.174	0.668	1.800
	6.000	1.013	3.035	0.687	1.700
30.000	4.000	1.664	3.730	0.636	2.300
	5.000	1.466	3.569	0.634	2.100
	6.000	1.316	3.425	0.684	2.000
	7.000	1.197	3.298	0.603	1.800
	8.000	1.102	3.185	0.698	1.800
40.000	5.000	1.758	3.871	0.642	2.400
	6.000	1.581	1.581	0.619	2.200
	7.000	1.441	3.594	0.659	2.100
	8.000	1.328	3.477	0.672	2.000
50.000	6.000	1.822	3.972	0.678	2.500
	7.000	1.663	3.839	0.637	2.300
	8.000	1.534	3.718	0.666	2.200
	10.000	1.336	3.510	0.664	2.000

Table 2-17 Uniform Flow Depth of Spillway Downstream Channel

uniform flow depth

Discharge (m^3/s)	Channel width B (m)	Slope %	Water Depth D1 (m)	Velocity V1 (m/s)	Freeboard F (m)	Channel Depth CD (m)
1.000	1.000	20.000	0.141	6.609	0.659	0.800
	1.000	10.000	0.175	5.249	0.625	0.800
	1.000	5.000	0.217	4.154	0.683	0.900
	1.000	1.000	0.357	2.374	0.643	1.000
5.000	1.000	20.000	0.383	10.965	0.617	1.000
	1.000	10.000	0.473	8.545	0.627	1.100
	1.000	5.000	0.583	6.634	0.617	1.200
	1.000	1.000	0.936	3.639	0.664	1.600
10.000	2.000	20.000	0.374	12.209	0.626	1.000
	2.000	10.000	0.464	9.649	0.636	1.100
	2.000	5.000	0.576	7.595	0.624	1.200
	2.000	1.000	0.944	4.285	0.656	1.600
15.000	3.000	20.000	0.370	12.739	0.630	1.000
	3.000	10.000	0.458	10.141	0.642	1.100
	3.000	5.000	0.568	8.044	0.632	1.200
	3.000	1.000	0.935	4.626	0.665	1.600
20.000	4.000	20.000	0.367	13.032	0.633	1.000
	4.000	10.000	0.454	10.419	0.646	1.100
	4.000	5.000	0.563	8.304	0.637	1.200
	4.000	1.000	0.926	4.838	0.674	1.600
30.000	6.000	20.000	0.364	13.346	0.636	1.000
	6.000	10.000	0.450	10.720	0.650	1.100
	6.000	5.000	0.556	8.592	0.644	1.200
	6.000	1.000	0.914	5.084	0.686	1.600
40.000	8.000	20.000	0.362	13.511	0.638	1.000
	8.000	10.000	0.447	10.881	0.653	1.100
	8.000	5.000	0.553	8.747	0.647	1.200
	8.000	1.000	0.906	5.223	0.694	1.600
50.000	10.000	20.000	0.361	13.613	0.639	1.000
	10.000	10.000	0.445	10.980	0.655	1.100
	10.000	5.000	0.550	8.844	0.650	1.200
	10.000	1.000	0.901	5.312	0.699	1.600

Table 2-18 Hydraulic Calculation of Energy Dissipater (Stilling Basin)

Energy Dissipater (Stilling Basin)

Discharge (m^3/s)	Channel width B (m)	Slope of steep channel %	Depth before jump D1 (m)	Velocity V1 (m/s)	Froude number Fr	Depth after jump D2(m)	Freeboard Fb (m)	Length L(m)	Channel Depth CD (m)
1.000	1.000	20.000	0.141	6.609	5.622	1.053	0.766	6.317	1.819
	1.000	10.000	0.175	5.249	4.008	0.908	0.616	5.450	1.524
	1.000	5.000	0.217	4.154	2.849	0.772	0.493	3.090	1.265
	1.000	1.000	0.357	2.374	1.269	0.487	0.286	1.947	0.773
5.000	1.000	20.000	0.383	10.965	5.660	2.880	1.385	17.280	4.265
	1.000	10.000	0.473	8.545	3.969	2.429	1.097	9.716	3.526
	1.000	5.000	0.583	6.634	2.775	2.015	0.865	8.061	2.880
	1.000	1.000	0.936	3.639	1.202	1.190	0.483	4.760	1.673
10.000	2.000	20.000	0.374	12.209	6.377	3.191	1.540	19.147	4.731
	2.000	10.000	0.464	9.649	4.525	2.746	1.240	16.478	3.986
	2.000	5.000	0.576	7.595	3.197	2.332	0.993	9.328	3.325
	2.000	1.000	0.944	4.285	1.409	1.467	0.575	5.868	2.042
15.000	3.000	20.000	0.370	12.739	6.690	3.320	1.606	19.923	4.926
	3.000	10.000	0.458	10.141	4.787	2.880	1.302	17.279	4.182
	3.000	5.000	0.568	8.044	3.409	2.469	1.051	9.878	3.521
	3.000	1.000	0.935	4.626	1.528	1.607	0.623	6.427	2.230
20.000	4.000	20.000	0.367	13.032	6.872	3.388	1.642	20.326	5.030
	4.000	10.000	0.454	10.419	4.940	2.953	1.337	17.715	4.290
	4.000	5.000	0.563	8.304	3.535	2.547	1.085	10.189	3.632
	4.000	1.000	0.926	4.838	1.606	1.691	0.653	6.762	2.343
30.000	6.000	20.000	0.364	13.346	7.066	3.460	1.681	20.760	5.141
	6.000	10.000	0.450	10.720	5.105	3.031	1.375	18.189	4.407
	6.000	5.000	0.556	8.592	3.681	2.630	1.122	10.518	3.752
	6.000	1.000	0.914	5.084	1.699	1.786	0.687	7.143	2.473
40.000	8.000	20.000	0.362	13.511	7.173	3.496	1.701	20.975	5.196
	8.000	10.000	0.447	10.881	5.199	3.071	1.395	18.423	4.466
	8.000	5.000	0.553	8.747	3.757	2.675	1.142	10.700	3.817
	8.000	1.000	0.906	5.223	1.753	1.838	0.706	7.352	2.544
50.000	10.000	20.000	0.361	13.613	7.237	3.519	1.713	21.113	5.232
	10.000	10.000	0.445	10.980	5.258	3.094	1.407	18.563	4.501
	10.000	5.000	0.550	8.844	3.809	2.701	1.154	10.803	3.855
	10.000	1.000	0.901	5.312	1.788	1.871	0.718	7.486	2.590

Fr = V1/(gxD1)^0.5
D2 = 1/2x((1+8Fr^2)^0.5-1)xD1
Fb = 0.1x(V1+D2)
L = 6xD2 (Fr>4), 4xD2 (Fr<4)

The larger the over flow depth is, the higher the embankment is required, and the smaller the overflow depth is, the larger the channel. The flow velocity at inlet channel should be less than 4.0 m/sec to ensure gentle flow with small fluctuation of water surface. In case that driftwood and trash is expected to flow in, the depth should be not less than 0.4 m. The over flow depth at the spillway: 0.4~1.0 m. The flow velocity at inlet channel: less than 4.0 m/sec. The slope of spillway downstream channel: steeper than 1%.

From above hydraulic analysis, recommended dimensions of spillway are shown in the **Table 2-19**.

Table 2-19 Standard Dimensions of Spillway

Flood Discharge (m^3/sec)	~5.0 m^3	5.0 ~ 10.0 m^3	10.0~ 20.0 m^3	20.0~ 30.0 m^3	30.0 ~ 40.0 m^3	40.0~ 50.0 m^3
Inlet Culvert Channel Width (m)	7.5	-	-	-	-	-
Inlet Culvert Channel Depth (m)	1.9	-	-	-	-	-
Inlet Open Channel Width (m)	3.0	6.0	12.0	18.0	24.0	30.0
Inlet Open Channel Depth (m)	2.0	2.0	2.0	2.0	2.0	2.0
Spillway Downstream Channel Width, End Point (m)	2.0	2.0	4.0	6.0	8.0	10.0
Spillway Downstream Channel Depth, End Point (m)	1.5	1.9	1.9	2.0	2.0	2.0
Steep Channel width (m)						
Slope 20%	1.0	2.0	4.0	6.0	8.0	10.0
Slope 10%	1.0	2.0	4.0	6.0	8.0	10.0
Slope 5%	1.0	2.0	4.0	6.0	8.0	10.0
Slope 1%	1.0	2.0	4.0	6.0	8.0	10.0
Steep Channel Depth (m)						
Slope 20%	1.0	1.0	1.0	1.0	1.0	1.0
Slope 10%	1.1	1.1	1.1	1.1	1.1	1.1
Slope 5%	1.2	1.2	1.2	1.2	1.2	1.2
Slope 1%	1.6	1.6	1.6	1.6	1.6	1.6
Stilling Basin Length (m)						
Slope of steep channel 20%	17.3	19.2	20.4	20.8	21.0	21.2
Slope of steep channel 10%	9.8	16.5	17.8	18.2	18.5	18.6
Slope of steep channel 5%	8.1	9.4	10.2	10.6	10.7	10.9
Slope of steep channel 1%	4.8	5.9	6.8	7.2	7.4	7.5
Stilling Basin Width (m)						
Slope of steep channel 20%	1.0	2.0	4.0	6.0	8.0	10.0
Slope of steep channel 10%	1.0	2.0	4.0	6.0	8.0	10.0
Slope of steep channel 5%	1.0	2.0	4.0	6.0	8.0	10.0
Slope of steep channel 1%	1.0	2.0	4.0	6.0	8.0	10.0
Stilling Basin Depth (m)						
Slope of steep channel 20%	4.3	4.8	5.1	5.2	5.2	5.3
Slope of steep channel 10%	3.6	4.0	4.3	4.5	4.5	4.6
Slope of steep channel 5%	2.9	3.4	3.7	3.8	3.9	3.9
Slope of steep channel 1%	1.7	2.1	2.4	2.5	2.6	2.6

5) Intake and outlet

The structures of intake facilities and outlet works should safely intake maximum intake volume or to safely release maximum outlet discharge. The structures should not to produce any adverse effects on dam body, foundation and reservoir. In this guideline, intake and outlet facilities should be composed of intake pit, sluice gate, bottom conduit, discharge pipe, valve and outlet box.

(i) Intake pit

Intake pit should be made of concrete or bricks. It is desirable that a screen is installed not to make trash inflow the bottom conduit. Broken part should be repaired with mortar. Sediment inside and around the pit should be removed every year

ii) Bottom conduit

Diameter of bottom conduit should be not be less than 0.45m considering maintenance. Bottom conduit should have enough strength against soil pressure. Bottom conduit should be constructed in the foundation with smooth contact between conduit and dam body, and safe design against external pressure and seepage. Cut-off wall should be provided to prevent leakage and piping. Specialist should be engaged when assessing whether a structure needs repair or not.

iii) Valve and gate

Valve and gate should have necessary water tightness, durability and operational performance. In the case these are not functional; they should be repaired or replaced.

iv) Discharge Pipe

Discharge Pipe conveys water to outlet pit. PVC discharge pipes are recommended.

v) Outlet box

Water is released in discharge box and flow into main canal. Discharge box should be a structure, which dissipate water energy. Broken part should be repaired with mortar.

The hydraulic analysis of intake system is shown in **Figure 2-12** and is carried out as follows. Table of coefficients from **Table 2-20 ~Table 2-25** are used in the process of the Analysis.

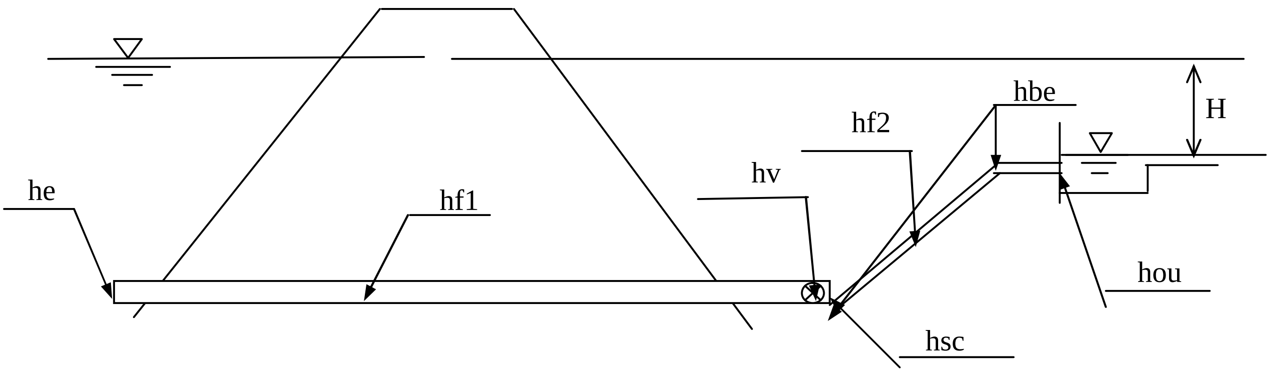


Figure 2-12 Standard Intake System

he: inflow head loss (m)
he = fe x V2/2g
fe: coefficient of inflow head loss

Table 2-20 Coefficient of Inflow Head Loss

Shape of inlet	Square	Cutting corner	Circular corner	Bellmouse
Fe	0.5	0.25	0.1~0.2	0.01~0.05

V: mean velocity after inflow (m/s)
g: acceleration of gravity (m/s2)
hf1: friction head loss of intake conduit
hf1 = f x L/D x V2/2g (m)
L: length of the pipe (m)
D: Diameter of the pipe (m)
f: coefficient of friction head loss

f = 133.7/(C1.85 x D0.167 x V0.148)
C: coefficient of velocity

Table 2-21 Coefficient of Velocity

Pipe (inside condition)	Coefficient of velocity		
	Maximum value	Minimum value	Standard value
Cast iron pipe (not painted)	150	80	100
Steel pipe (not painted)	150	90	100
Coal-tar painted pipe (Cast iron)	145	80	100
Tar epoxy painted pipe (Steel)			
ϕ 800~	-	-	130
ϕ 700~600	-	-	120
ϕ 500~350	-	-	110
ϕ 300~	-	-	100
Mortar lining pipe (Steel, Cast iron)	150	120	130
Reinforced concrete pipe	140	120	130
Prestressed concrete pipe	140	120	130
Chloride vinyl pipe *	160	140	150
Polyethylene pipe *	170	130	150
Reinforced plastic pipe *	160	-	150

* C=140 is adopted as standard value for the pipes having diameter less than 150mm.
hv: valve head loss
hv = fv x V2/2g (m)
fv: coefficient of valve head loss

Table 2-22 Coefficient of Valve Head Loss by Weisbach

Gate valve, circular pipe (D=610, 762mm)
S: opening of valve, D: diameter, a: area of opening, A: area of full opening

S/D =	0.05	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80
a/A =	0.05	0.10	0.23	0.36	0.48	0.60	0.71	0.81	0.89
fv (D-610mm) =	235	100	28	11	5.6	3.2	1.7	0.95	-
fv (D-762mm) =	333	111	23	9.4	5.2	3.1	1.9	1.13	0.60

Butterfly valve, (full open: θ =0° , close: θ =90°)
a: area of opening, A: area of full opening, θ : opening angle

θ =	5	10	15	20	25	30	35	40	45	50	60	70	90
a/A =	0.91	0.83	0.74	0.66	0.58	0.50	0.43	0.36	0.29	0.23	0.13	0.06	0.0
fv =	0.24	0.52	0.90	1.54	2.51	3.91	6.22	10.8	18.7	32.6	118	751	∞

hsc: sudden contraction head loss
hsc = fsc x V22/2g
V2: mean velocity after sudden contraction (m/s)
fsc: coefficient of sudden contraction head loss

Table 2-23 Coefficient of Sudden Contraction Head Loss

D2/D1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
fsc	0.50	0.50	0.49	0.49	0.46	0.43	0.38	0.29	0.18	0.07

D2: Diameter after sudden contraction
D1: Diameter before sudden contraction
hse: sudden enlargement head loss
hse = fse x V12/2g
V1: mean velocity before sudden enlargement (m/s)
fse: coefficient of sudden enlargement head loss

Table 2-24 Coefficient of Sudden Enlargement Head Loss

D1/D2	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
fse	1.0	0.98	0.92	0.82	0.70	0.56	0.41	0.26	0.13	0.04

D2: Diameter after sudden enlargement
D1: Diameter before sudden enlargement
hf2: friction head loss of discharge pipeline
hf1 = f x L/D x V2/2g (m)
L: length of the pipe (m)
D: Diameter of the pipe (m)
f: coefficient of friction head loss
f = 133.7/ (C1.85 x D0.167 x V0.148)
C: coefficient of velocity
hbe: bend head loss
hbe = fbe x V2/2g (m)
fbe: coefficient of bend pipe head loss

Table 2-25 Coefficient of Bend Pipe Head Loss by Weisbach

θ	15	30	45	60	90	120
Fbe	0.022	0.073	0.183	0.365	0.99	1.86

θ =: bend angle °
hou: outflow head loss
hou = fou x V2/2g, fou = 1.0
H = he + hf1 + hv + hsc + hf2 + hbe + hou

Table 2-26 shows example of hydraulic analysis of intake system.

The condition of analysis;
D1: 0.45 m, 0.60 m, 0.90 m
D2: 0.11 m, 0.14 m,
L1: 25 m
L2: 100 m
fe = 0.5
fv = 0 (full open)
fbe = 0.073 (θ = 30°)
fou = 1.0

(Ref. Design Standard of Pipeline, Ministry of Agriculture and Fishery, Japan, 1998)

(4) Rehabilitation plan

Rehabilitation plan should be made based on investigation result. From the investigation result, rehabilitation items are studied and rehabilitation work is planned. Rehabilitation work should be planned to make the dam and facilities functional and safe to meet the condition and standard described in this guideline.

Table 2-26 Hydraulic Analysis of Intake System (Example)

Hydrulic Analysis of Intake System (Example)

Q	D1	V1	he	hf1	D2	fsc	V2	hsc	hbe	f2	hf2	hou	H
0.005	0.450	0.031	0.000	0.000	0.110	0.490	0.526	0.007	0.002	0.023	0.292	0.014	0.315
0.005	0.600	0.018	0.000	0.000	0.110	0.490	0.526	0.007	0.002	0.023	0.292	0.014	0.315
0.005	0.900	0.008	0.000	0.000	0.110	0.500	0.526	0.007	0.002	0.023	0.292	0.014	0.315
0.010	0.450	0.063	0.000	0.000	0.110	0.490	1.052	0.028	0.008	0.021	1.055	0.056	1.148
0.010	0.600	0.035	0.000	0.000	0.110	0.490	1.052	0.028	0.008	0.021	1.055	0.056	1.147
0.010	0.900	0.016	0.000	0.000	0.110	0.500	1.052	0.028	0.008	0.021	1.055	0.056	1.148
0.015	0.450	0.094	0.000	0.001	0.110	0.490	1.578	0.062	0.019	0.019	2.235	0.127	2.444
0.015	0.600	0.053	0.000	0.000	0.110	0.490	1.578	0.062	0.019	0.019	2.235	0.127	2.443
0.015	0.900	0.024	0.000	0.000	0.110	0.500	1.578	0.064	0.019	0.019	2.235	0.127	2.445
0.020	0.450	0.126	0.000	0.001	0.110	0.490	2.105	0.111	0.033	0.019	3.808	0.226	4.179
0.020	0.600	0.071	0.000	0.000	0.110	0.490	2.105	0.111	0.033	0.019	3.808	0.226	4.178
0.020	0.900	0.031	0.000	0.000	0.110	0.500	2.105	0.113	0.033	0.019	3.808	0.226	4.180
0.030	0.450	0.189	0.001	0.002	0.110	0.490	3.157	0.249	0.074	0.017	8.069	0.508	8.904
0.030	0.600	0.106	0.000	0.001	0.110	0.490	3.157	0.249	0.074	0.017	8.069	0.508	8.902
0.030	0.900	0.047	0.000	0.000	0.110	0.500	3.157	0.254	0.074	0.017	8.069	0.508	8.906
0.040	0.450	0.252	0.002	0.004	0.110	0.490	4.209	0.443	0.132	0.017	13.747	0.904	15.232
0.040	0.600	0.141	0.001	0.001	0.110	0.490	4.209	0.443	0.132	0.017	13.747	0.904	15.228
0.040	0.900	0.063	0.000	0.000	0.110	0.500	4.209	0.452	0.132	0.017	13.747	0.904	15.236
0.005	0.450	0.031	0.000	0.000	0.140	0.490	0.325	0.003	0.001	0.023	0.090	0.005	0.099
0.005	0.600	0.018	0.000	0.000	0.140	0.490	0.325	0.003	0.001	0.023	0.090	0.005	0.099
0.005	0.900	0.008	0.000	0.000	0.140	0.490	0.325	0.003	0.001	0.023	0.090	0.005	0.099
0.010	0.450	0.063	0.000	0.000	0.140	0.490	0.650	0.011	0.003	0.021	0.326	0.022	0.362
0.010	0.600	0.035	0.000	0.000	0.140	0.490	0.650	0.011	0.003	0.021	0.326	0.022	0.361
0.010	0.900	0.016	0.000	0.000	0.140	0.490	0.650	0.011	0.003	0.021	0.326	0.022	0.361
0.015	0.450	0.094	0.000	0.001	0.140	0.490	0.974	0.024	0.007	0.020	0.690	0.048	0.771
0.015	0.600	0.053	0.000	0.000	0.140	0.490	0.974	0.024	0.007	0.020	0.690	0.048	0.770
0.015	0.900	0.024	0.000	0.000	0.140	0.490	0.974	0.024	0.007	0.020	0.690	0.048	0.770
0.020	0.450	0.126	0.000	0.001	0.140	0.490	1.299	0.042	0.013	0.019	1.176	0.086	1.319
0.020	0.600	0.071	0.000	0.000	0.140	0.490	1.299	0.042	0.013	0.019	1.176	0.086	1.318
0.020	0.900	0.031	0.000	0.000	0.140	0.490	1.299	0.042	0.013	0.019	1.176	0.086	1.317
0.030	0.450	0.189	0.001	0.002	0.140	0.490	1.949	0.095	0.028	0.018	2.493	0.194	2.813
0.030	0.600	0.106	0.000	0.001	0.140	0.490	1.949	0.095	0.028	0.018	2.493	0.194	2.811
0.030	0.900	0.047	0.000	0.000	0.140	0.490	1.949	0.095	0.028	0.018	2.493	0.194	2.810
0.040	0.450	0.252	0.002	0.004	0.140	0.490	2.598	0.169	0.050	0.017	4.247	0.344	4.816
0.040	0.600	0.141	0.001	0.001	0.140	0.490	2.598	0.169	0.050	0.017	4.247	0.344	4.812
0.040	0.900	0.063	0.000	0.000	0.140	0.490	2.598	0.169	0.050	0.017	4.247	0.344	4.811

2.3 Motorized Pump

Motorized pump system had been introduced in the country sometime back but many of them are not functioning due to lack of maintenance technical capacity and lack of finances for operation and maintenance of the structures. Sprinkler system with motorized pump had been tried and abandoned due maintenance difficulties. Since many of farmers prefer surface irrigation to sprinkler irrigation, the guideline concentrates on the surface irrigation with motorized pump system. The system consists of pump, discharge pipe, discharge box, main canal and division box.

(1) Rehabilitation/Construction Criteria

1) Material

Most of materials for rehabilitation work are sourced/procured locally and input from outside are minimized. Local materials include sand, stone, bricks and cement, gabion, tools are outside materials.

2) Labor

The rehabilitation work is recommended to be done by the farmers under supervision of AEDO and IOs. Labor force should be provided by the farmers association. Only transportation for materials (if necessary) could be provided from outside.

(2) Investigation

Field investigations should be carried out at and around the site on necessary items for design, construction, rehabilitation and O&M. Prior to the investigations selecting necessary items for investigation, the appropriate investigation plan should be put in practice. The results of investigation are necessary for design of pump system and canal system.

1) Meteorological and hydrological investigations

Meteorological and hydrological conditions of the site should be investigated through data collection and observation. Items for meteorological and hydrological investigation include temperature, precipitation, evaporation, wind direction, wind velocity.

2) Investigation for water source conditions

This investigation is performed to clarify the present water source (river or pond) conditions. Investigation items include flow quantity, water level, available storage capacity of the pond, water temperature, water quality, riverbed conditions etc.

3) Topographic investigations

Topography of the site and surrounding area should be clarified through data collection and topographic survey. Topographic investigations are important to determine the location of the pump and canal system.

4) Investigation for Operation and maintenance

Investigation for operation and maintenance should be executed on following items;

i) Meteorology, hydrology
ii) Water source conditions
iii) Condition of existing pump system
iv) Data on water use management of existing pump
v) Operation and maintenance system of existing pump

5) Investigation for construction works

Investigation for construction works should be conducted on the following items, which are necessary for construction planning.

(i) Meteorology, surface water, ground water
Meteorology and surface water should be thoroughly investigated because of their utmost importance for deciding the construction schedule. Especially, temperature is important for planning concrete (mortar) works.
(ii) Construction equipment and materials
Construction materials include cement, soil, sand, gravel, stone, steel materials, bricks and timber etc. The supply situation of materials should be checked. Availability of local materials, necessity of transportation, availability of transportation and availability of tools should be checked. Transportation of materials should be arranged if necessary. Refer to the **Table 2-27.**

Table 2-27 List of Items to be Investigated (Motorized Pump Irrigation)

Items	Description	Method	Outputs
1.Meteorological and hydrological investigations	- Collection of meteorological and hydrological data	Data collection and site observation	Annual rainfall, Temp., wind direction, wind velocity, etc.
2. Water source conditions (i) Water level and discharge (ii) Stream	- Highest water level and lowest water level - Representative water level and flow velocity in each month - Capacity of the pond - Stream centerline is stable - Stream at the intake point is stable	Observation of past flood mark and villagers interview Observation at the river Derive from topographic survey Visual observation at the river	HWL = LWL = WL= V = m^3 Yes or No Yes or No Stones, sand or silt.

(iii) Sedimentation (iv) Riverbed (v) River Utilisation	- Sediment at the intake point - Riverbed slope - Materials and conditions of the river - Water Rights	Observation of sediment configuration. Surveying. 20m interval, from 100m upstream to 100m downstream. Visual observation at the river Interview to relevant party	A lot of or a little Riverbed slope = Estimated roughness coefficient = Quantity = lit/s Water fee= MK
3. Topographic investigations (i) Pump location and surroundings (ii) Collection of topographic and other related maps.	- Configuration of the river, location of the pump, contour line etc. should be indicated. - Longitudinal section of the pipeline. - Available maps around the scheme	Site surveying with measuring tape and compass. Plane table. Site surveying with measuring tape and level Data collection	Plan: scale 1/1000~1/2000 Longitudinal section: scale 1/200~1/500 Actual pump head= m Various maps
4. Operation and maintenance (i) Condition of existing pump system (ii) Data on water use management (iii) Operation and maintenance of existing pump	- Condition of engine - Condition of pump - Function of pump - Condition of suction pipe - Condition of discharge pipe - Condition of discharge box - Daily operation hour and intake water level - Fuel consumption, oil and spare parts replacement	Trial operation, checking maintenance items Trial operation, checking maintenance items Trial operation Visual inspection Visual inspection Visual inspection, measuring tape Operation and maintenance record of the pump Operation and Maintenance record of the pump	Good/bad Need repair or not Maintenance check list Good/bad Damage, leakage Damage, leakage Dimensions, material, damage, cracks Irrigation schedule, daily, Q for the canal Fuel consumption, necessity of maintenance
5. Construction works (i) Meteorology (ii) Construction equipment, materials, transportation	- Collection of all existing meteorological data - Availability of materials - Number of available tools - Available transportation - Labor availability	Data collection and site observation Sand Cement Wheelbarrow Bucket, Shovel, Others Truck, tractor, oxcart Skilled labor Unskilled labor	Annual rainfall, Stream condition, temp., water level = km from the site = to be procured in__ = units = pcs DAO, DA, ADD, Farmers = number

(3) Rehabilitation/Construction Planning/Design

1) General Layout

General layout of pump irrigation system is shown in the **Figure 2-13**.

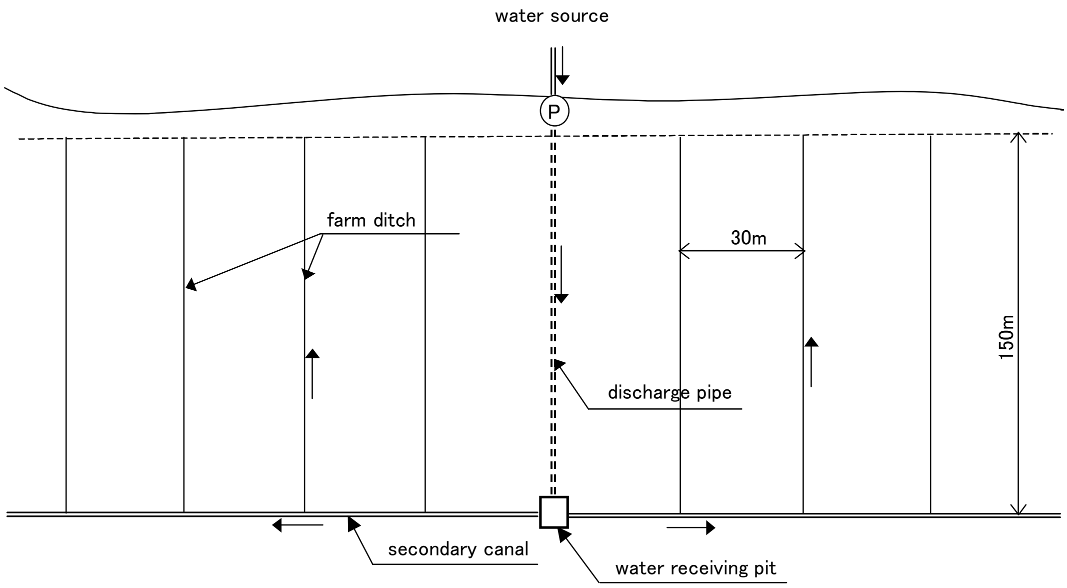


Figure 2-13 General Lay-out of Pump Irrigation System

Water is pumped up from water source (river or pond) and conveyed to discharge box through discharge pipe. Water is discharged from discharge box to secondary canal, and from secondary canal to farm ditch. Recommended size of one plot is 30m x 150m, 0.45 ha considering conveyance of water in the field.

2) Discharge Pipe

Discharge pipes are recommended steel, galvanized steel or PVC. Diameter of the pipe should be determined by hydraulic analysis. Discharge pipes should be installed under ground to the depth that the soil cover is more than 30 cm, refer to the **Figure 2-14**. In case of diameter 110 mm and 160mm, 30 cm soil cover is enough safe for gross weight 14 ton truck load. Soil cover should be determined considering cultivation.

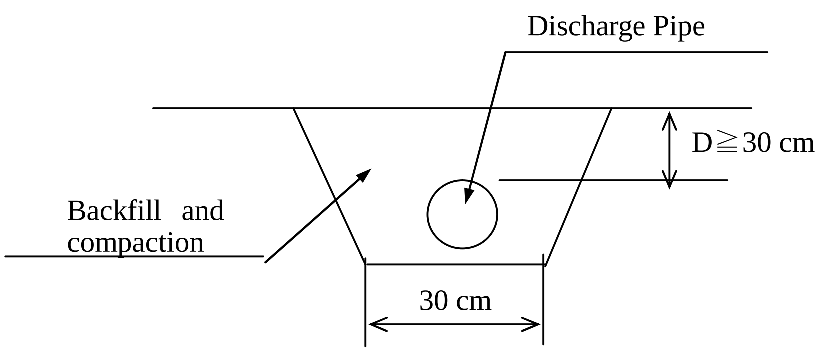


Figure 2-14 Standard Installation of Discharge Pipe

3) Discharge Box

Discharge box should be made of concrete or bricks. Standard type of discharge box, Plan View and Cross Sections are shown in **Figure 2-15.**

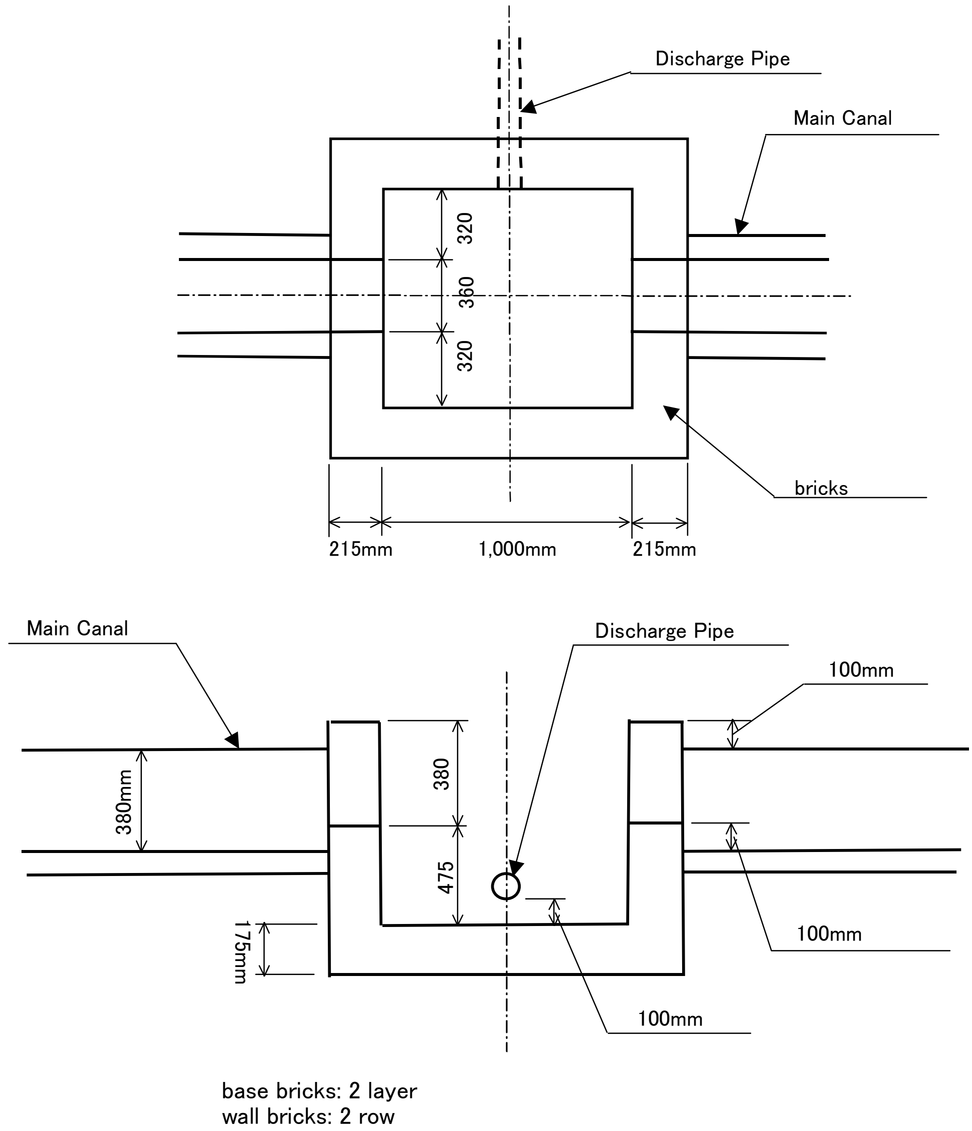


Figure 2-15 Standard Type of Discharge Box (Plan and Cross Section Views)

4) Pump

Pump facilities should be safely secured and economically designed for maximum discharge. It should be decided after thorough examination of discharge fluctuation, the relationship with other facilities, operation and maintenance. In designing pump facilities, the following parameters should be decided;

(i) Number of pump facilities
Usually, a pumping station has multiple pumps and one of them is prepared as a backup pump. However, in a medium scale irrigation scheme, backup pump is not prepared considering economical efficiency.

(ii) Type of pump
In Malawi, small scale centrifugal volute pump is common and its spare parts are available. In the case of no pump house, transportable type of pump is recommended considering storing in the rainy season.

(iii) Pump diameter
Generally, diameter of small scale pump ranges from 75mm to 150mm. The diameter should be determined considering required pump capacity and discharge.

(iv) Discharge (per unit)
Discharge flow quantity should be determined based on maximum water requirement of the field.

(v) Total pumping head
Total pumping head is actual pump head + total head loss. The pump should be selected considering total pumping head and discharge. The pump capacity should have enough discharge capacity at the required total pumping head. The pump capacity is read out from the pump characteristic curve of each pump.

vi) Type and output of engine
A Pump is driven by motor, gasoline engine or diesel engine. In Malawi, generally electric power is not available at the site and many diesel engine driven pumps are used in medium scale schemes. The output of engine should be determined based on the characteristic curve at each output.

Hydraulic Conditions of the Pump System are shown in **Figure 2-16.**

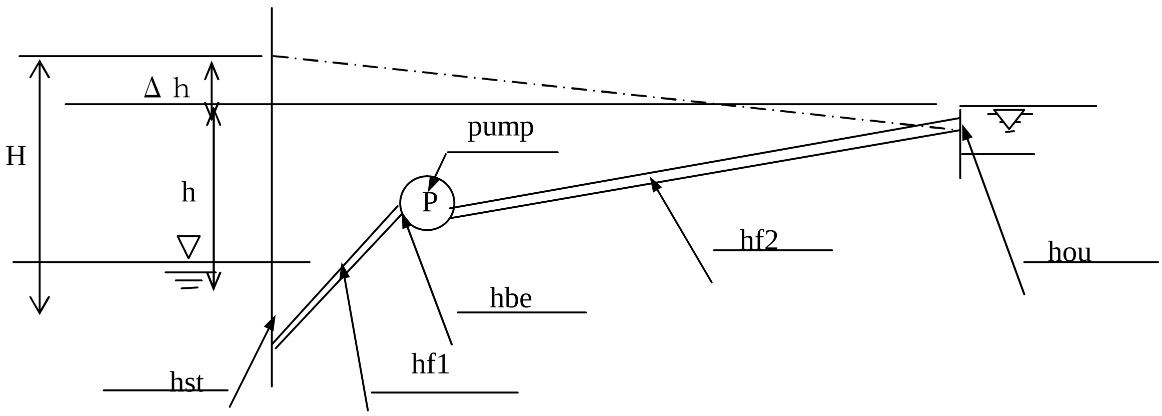


Figure 2-16 Hydraulic Condition of Pump System

H = h + Δh
H: Total Pump Head (m)
h: Actual Pump Head (m)
Δh: Total Head Loss (m)
hst: strainer head loss (m)
hst = fst x $V^2/2g$ (m)
f: coefficient of strainer head loss, f = 1.0
hf1: friction head loss of suction pipe (m)
hbe: bend pipe head loss (m)
hbe = fbe x $V^2/2g$ (m)
fbe = 0.183 (45°)
hf2: friction head loss of discharge pipe (m)
hou: out flow head loss (m)
hou = fou x $V^2/2g$ (m)
f: coefficient of strainer head loss, f = 1.0

Hydraulic analysis is carried out as same as 2.2 (3) 5). **Table 2-28** shows example of hydraulic analysis of pipeline system. The condition of analysis;

Suction pipe: Polyethylene hose, Diameter D1 = 100 mm, 140 mm, Length L1 = 10m
Discharge pipe: PVC, Diameter D2 = 110 mm, 140 mm, 200 mm, Length L2 = 200 m, 300 m, 400m
Discharge: 5, 10, 15, 20 lit/sec

Table 2-28 Hydraulic Analysis of Pipeline System (Example)

D1=0.1m, L1=10.0m D2=0.11m, L2=200.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.100	0.637	0.021	0.022	0.046	0.004	0.110	0.526	0.023	0.584	0.014	0.669
0.010	0.100	1.273	0.083	0.020	0.168	0.015	0.110	1.052	0.021	2.110	0.056	2.432
0.015	0.100	1.910	0.186	0.019	0.356	0.034	0.110	1.578	0.019	4.471	0.127	5.173
0.020	0.100	2.546	0.331	0.018	0.606	0.061	0.110	2.105	0.019	7.616	0.226	8.840

D1=0.1m, L1=10.0m D2=0.11m, L2=300.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.100	0.637	0.021	0.022	0.046	0.004	0.110	0.526	0.023	0.877	0.014	0.962
0.010	0.100	1.273	0.083	0.020	0.168	0.015	0.110	1.052	0.021	3.165	0.056	3.487
0.015	0.100	1.910	0.186	0.019	0.356	0.034	0.110	1.578	0.019	6.706	0.127	7.409
0.020	0.100	2.546	0.331	0.018	0.606	0.061	0.110	2.105	0.019	11.424	0.226	12.648

D1=0.1m, L1=10.0m D2=0.11m, L2=400.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.100	0.637	0.021	0.022	0.046	0.004	0.110	0.526	0.023	1.169	0.014	1.254
0.010	0.100	1.273	0.083	0.020	0.168	0.015	0.110	1.052	0.021	4.220	0.056	4.542
0.015	0.100	1.910	0.186	0.019	0.356	0.034	0.110	1.578	0.019	8.941	0.127	9.644
0.020	0.100	2.546	0.331	0.018	0.606	0.061	0.110	2.105	0.019	15.233	0.226	16.456

D1=0.1m, L1=10.0m D2=0.14m, L2=200.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.100	0.637	0.021	0.022	0.046	0.004	0.140	0.325	0.023	0.181	0.005	0.257
0.010	0.100	1.273	0.083	0.020	0.168	0.015	0.140	0.650	0.021	0.652	0.022	0.939
0.015	0.100	1.910	0.186	0.019	0.356	0.034	0.140	0.974	0.020	1.381	0.048	2.005
0.020	0.100	2.546	0.331	0.018	0.606	0.061	0.140	1.299	0.019	2.353	0.086	3.436

D1=0.1m, L1=10.0m D2=0.14m, L2=300.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.100	0.637	0.021	0.022	0.046	0.004	0.140	0.325	0.023	0.271	0.005	0.347
0.010	0.100	1.273	0.083	0.020	0.168	0.015	0.140	0.650	0.021	0.978	0.022	1.265
0.015	0.100	1.910	0.186	0.019	0.356	0.034	0.140	0.974	0.020	2.071	0.048	2.696
0.020	0.100	2.546	0.331	0.018	0.606	0.061	0.140	1.299	0.019	3.529	0.086	4.612

D1=0.14m, L1=10.0m D2=0.14m, L2=300.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.140	0.325	0.005	0.023	0.009	0.001	0.140	0.325	0.023	0.271	0.005	0.292
0.010	0.140	0.650	0.022	0.021	0.033	0.004	0.140	0.650	0.021	0.978	0.022	1.057
0.015	0.140	0.974	0.048	0.020	0.069	0.009	0.140	0.974	0.020	2.071	0.048	2.246
0.020	0.140	1.299	0.086	0.019	0.118	0.016	0.140	1.299	0.019	3.529	0.086	3.835

D1=0.14m, L1=10.0m D2=0.14m, L2=400.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.140	0.325	0.005	0.023	0.009	0.001	0.140	0.325	0.023	0.361	0.005	0.382
0.010	0.140	0.650	0.022	0.021	0.033	0.004	0.140	0.650	0.021	1.303	0.022	1.383
0.015	0.140	0.974	0.048	0.020	0.069	0.009	0.140	0.974	0.020	2.762	0.048	2.937
0.020	0.140	1.299	0.086	0.019	0.118	0.016	0.140	1.299	0.019	4.706	0.086	5.011

D1=0.14m, L1=10.0m D2=0.20 m, L2=200.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.140	0.325	0.005	0.023	0.009	0.001	0.200	0.159	0.025	0.032	0.001	0.048
0.010	0.140	0.650	0.022	0.021	0.033	0.004	0.200	0.318	0.022	0.115	0.005	0.178
0.015	0.140	0.974	0.048	0.020	0.069	0.009	0.200	0.477	0.021	0.243	0.012	0.381
0.020	0.140	1.299	0.086	0.019	0.118	0.016	0.200	0.637	0.020	0.414	0.021	0.654

D1=0.14m, L1=10.0m D2=0.20m, L2=300.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.140	0.325	0.005	0.023	0.009	0.001	0.200	0.159	0.025	0.048	0.001	0.064
0.010	0.140	0.650	0.022	0.021	0.033	0.004	0.200	0.318	0.022	0.172	0.005	0.235
0.015	0.140	0.974	0.048	0.020	0.069	0.009	0.200	0.477	0.021	0.365	0.012	0.503
0.020	0.140	1.299	0.086	0.019	0.118	0.016	0.200	0.637	0.020	0.621	0.021	0.861

D1=0.14m, L1=10.0m D2=0.20m, L2=400.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.140	0.325	0.005	0.023	0.009	0.001	0.200	0.159	0.025	0.064	0.001	0.080
0.010	0.140	0.650	0.022	0.021	0.033	0.004	0.200	0.318	0.022	0.229	0.005	0.293
0.015	0.140	0.974	0.048	0.020	0.069	0.009	0.200	0.477	0.021	0.486	0.012	0.624
0.020	0.140	1.299	0.086	0.019	0.118	0.016	0.200	0.637	0.020	0.828	0.021	1.068

D1=0.1m, L1=10.0m D2=0.14m, L2=400.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.100	0.637	0.021	0.022	0.046	0.004	0.140	0.325	0.023	0.361	0.005	0.437
0.010	0.100	1.273	0.083	0.020	0.168	0.015	0.140	0.650	0.021	1.303	0.022	1.591
0.015	0.100	1.910	0.186	0.019	0.356	0.034	0.140	0.974	0.020	2.762	0.048	3.386
0.020	0.100	2.546	0.331	0.018	0.606	0.061	0.140	1.299	0.019	4.706	0.086	5.789

D1=0.1m, L1=10.0m D2=0.20m, L2=200.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.100	0.637	0.021	0.022	0.046	0.004	0.200	0.159	0.025	0.032	0.001	0.104
0.010	0.100	1.273	0.083	0.020	0.168	0.015	0.200	0.318	0.022	0.115	0.005	0.386
0.015	0.100	1.910	0.186	0.019	0.356	0.034	0.200	0.477	0.021	0.243	0.012	0.830
0.020	0.100	2.546	0.331	0.018	0.606	0.061	0.200	0.637	0.020	0.414	0.021	1.432

D1=0.1m, L1=10.0m D2=0.20m, L2=300.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.100	0.637	0.021	0.022	0.046	0.004	0.200	0.159	0.025	0.048	0.001	0.120
0.010	0.100	1.273	0.083	0.020	0.168	0.015	0.200	0.318	0.022	0.172	0.005	0.443
0.015	0.100	1.910	0.186	0.019	0.356	0.034	0.200	0.477	0.021	0.365	0.012	0.952
0.020	0.100	2.546	0.331	0.018	0.606	0.061	0.200	0.637	0.020	0.621	0.021	1.639

D1=0.1m, L1=10.0m D2=0.20m, L2=400.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.100	0.637	0.021	0.022	0.046	0.004	0.200	0.159	0.025	0.064	0.001	0.136
0.010	0.100	1.273	0.083	0.020	0.168	0.015	0.200	0.318	0.022	0.229	0.005	0.500
0.015	0.100	1.910	0.186	0.019	0.356	0.034	0.200	0.477	0.021	0.486	0.012	1.073
0.020	0.100	2.546	0.331	0.018	0.606	0.061	0.200	0.637	0.020	0.828	0.021	1.846

D1=0.14m, L1=10.0m D2=0.14m, L2=200.0m

Q m^3	D1 m	V1 m/s	hst m	f1	hf1 m	hbe m	D2 m	V2 m/s	f2	hf2 m	hou m	Δh m
0.005	0.140	0.325	0.005	0.023	0.009	0.001	0.140	0.325	0.023	0.181	0.005	0.201
0.010	0.140	0.650	0.022	0.021	0.033	0.004	0.140	0.650	0.021	0.652	0.022	0.731
0.015	0.140	0.974	0.048	0.020	0.069	0.009	0.140	0.974	0.020	1.381	0.048	1.556
0.020	0.140	1.299	0.086	0.019	0.118	0.016	0.140	1.299	0.019	2.353	0.086	2.658

Since when the flow velocity exceeds 1.0 m/sec, head loss becomes large, the pump is required of large capacity. It is recommended that the pipe diameter should be determined and that the flow velocity is less than 1.0 m/sec.

4) Main and Secondary Canal

Main canal and secondary canal should be developed as described in “2.4 Main Canal and Secondary Canal”.

2.4 Main Canal and Secondary Canal

Main canal conveys the diverted water from the intake point to the farming land. An associated problem with main canal is how to align structures according to the topographic condition without using sophisticated survey equipment. Construction, on the other hand, is not so difficult since most of the work required could be done with simple tools such as hoe, shovel, trowel etc. It is desirable that brick masonry canal should be used for main canal due to its easiness on maintenance and better water flow capacity than earth canal.

(1) Rehabilitation/Construction Criteria

1) Material

Most of materials for rehabilitation work should be locally sourced with minimum use of outside materials. Local materials include; sand, stone, bricks, soil etc. and cement, pipes and tools are inputs from outside.

2) Labor

The rehabilitation work should be done by the farmers under supervision of AEDOs and IOs. Labor force should be provided by the farmers association. Only transportation for materials (if necessary) should be provided from outside.

(2) Investigation

Field investigations should be carried out at and around the site on necessary items for design, construction, rehabilitation and O&M. Prior to the investigations selecting necessary items for investigation, the appropriate investigation plan should be put in practice. The results of investigation are essential for design of canal system.

1) Meteorological and hydrological investigations

Meteorological and hydrological conditions of the site should be investigated through data collection and observation. Items for meteorological and hydrological investigation include temperature, precipitation, evaporation, wind direction, wind velocity.

2) Soil and geological investigation

Soil tests of geological investigations, including the collection of geological data reconnaissance are important to be carried out along the proposed canal route to understand the geological structure, the physical properties of the soil, the ground water table and other conditions.

3) Topographic investigations

Topography of the site and surrounding area should be clarified through data collection and topographic survey. Topographic investigations are important to determine the alignment of canals and location of gully crossing and road crossing.

i) Plane survey
Plane survey is necessary for design of facilities and planning of construction. The location and route of canals, gully and road should be indicated. It is desirable to draw contour lines on the map.

ii) Longitudinal and cross section
Profile and cross section of the canal are used for determining canal alignment.

iii) Collection of topographic and other related maps
Prior to field investigations and surveys, topographic maps and other related maps around the scheme should be collected in order to prepare the investigation schedule, and to make a preliminary design.

4) Investigation for construction works

Investigation for construction works should be conducted on the following items, which are necessary for construction planning.

i) Meteorology, surface water, ground water
Meteorology and surface water should be thoroughly investigated because of their utmost importance for deciding the construction schedule. Especially, temperature is important for work plan of concrete (mortar) works.

ii) Construction equipment and materials
Construction materials include cement, soil, sand, gravel, stone, steel materials, bricks and timber etc. The supply situation of materials should be checked. Availability of local materials, necessity of transportation, availability of transportation and availability of tools should be checked. Transportation of materials should be arranged if necessary.

5) Investigation for rehabilitation of existing facilities

In case of rehabilitation of existing dam, following items should be investigated in addition to above items. (Refer to the **Table 2-29**)

i) Present condition of existing facilities
ii) Topographical survey for rehabilitation items
iii) Data on water use management of existing facilities.
iv) Operation and maintenance system of existing facilities

Table 2-29 List of Items to be Investigated (Main and Secondary Canal)

Items	Description	Method	Outputs
1.Meteorological and hydrological investigations	- Collection of meteorological and hydrological data	- Data collection and site observation	- Annual rainfall, temperature, wind direction, wind velocity,etc.
2. Soil and geological investigation			
(i) Geological data	- Collection of existing geological data	- Data collection	Topographic map, aerial photographs, geological map, soil texture, soil map
(ii) Surface geological survey	- To grasp the condition of the field	- Site surveying, observation	Ground water table = Soil character, unstable topography, gully
3. Topographic investigations			
(i) Plane survey	- Land topography, boundaries, existing structures, location of gully, location of road	- Site surveying with measuring tape and compass. Plane table	Plan: scale 1/1000~1/2000
(ii) Longitudinal and cross section	- Longitudinal section of canal center line - Cross section of canal center line	- Site survey with tape and level - ditto	Longitudinal section: scale 1/200~1/500 Cross section: scale 1/50
(iii) Collection of topographic and other related maps.	- Available maps around the scheme	- Data collection	Various maps

4. Construction works (i) Meteorology (ii) Construction equipment, materials, transportation	- Collection of all existing meteorological data - Availability of materials - Number of available tools - Available transportation - Number of available labor	- Data collection and site observation - Sand, Bricks, Cement - Wheelbarrow, Bucket, Shovel - Truck, tractor, oxcart - Skilled labor, Unskilled labor	Annual rainfall, Stream condition, temperature, water level = km from the site, = to be procured in___ = units, = pcs DAO, DA, ADD, Farmers = number
5. Rehabilitation of existing facilities (i) Present condition of existing facilities	-Dimensions of existing structures - Cracks - Damage of structures - Water leakage - Freeboard - Water flow condition - Function, capacity of canals - Sediment - Safety	- Site investigation, observation, measuring tape. - ditto - ditto - ditto - ditto - ditto - ditto - ditto - ditto	Length= m, width = m Depth= m, Elevation Location, length, width Location, situation Location, quantity = lit/min Fb= m Stable or not Enough or not Configuration and depth Good or bad
(ii) Topographical survey for rehabilitation items	- Longitudinal section of the structures to be rehabilitated. - Cross section of the structures to be rehabilitated.	- Site surveying with measuring tape and compass. Plane table.	Longitudinal section: scale 1/200~1/500 Cross section: scale 1/50
(iii) Investigation on water use management of existing canals	- Discharge - Irrigation schedule - Water flow depth	- Daily operation record	Daily discharge for the canal. Depth =
(iv) Operation and maintenance system of existing canals	- Operation and maintenance	- Operation and maintenance record	Operation and maintenance record.

(3) Rehabilitation/Construction Planning/Design

1) Canal Alignment

Recommended way of canal alignment is to use line level. Interval of the two poles should preferably be 5 meter, and one side of the tied points should be 0.5 – 1 cm higher than the other. Pole with higher tied point should always be placed foreside, not like conventional alternate placing. 0.5 cm difference in 5 meter gives 1:1000 gradient suitable for gentle topography, and 1 cm gives 1:500 gradient adaptable for sloped topography. **Figure 2-17** shows the process of canal alignment.

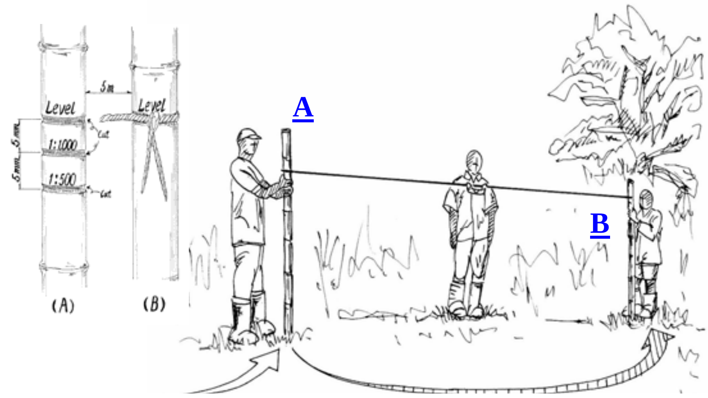


Figure 2-17 Illustration of Canal Alignment Procedure

2) Canal Lining

Canal is categorized into two; either non-lining or lined. Lining is made of brick or stone masonry (concrete lining is sometimes seen but the cost beyond farmers' affordability excludes this option).

Earth canal is the most simple and economical. With simple tools such as hoe, hand shovel, and wheelbarrow, construction is very easy and cheap. However, since this is non-lining, water conveyance loss is high due to seepage/leakage and much maintenance works such as grass cutting, de-silting, reshaping of cross section and so on are needed in every season.

Lining can be done with clay soil, plastic paper, stone, brick, or masonry. These canals reduce the canal conveyance loss and also minimize maintenance works as compared to earth canal. In particular, reducing the canal conveyance loss becomes very important when diversion water is not enough to cover all the prospective service area. Lining can also prevent the canal from being eroded, which in turn minimizes the maintenance work and makes canal life longer.

Investment for lining, on the other hand, is higher than earth canal except for clay, stone and recycled plastic paper linings. Farmers in rural area make bricks by themselves. Therefore, brick lining is cheaper than stone masonry, and damaged parts or bricks can easily be replaced by the farmers. Stone masonry lining is more durable than brick, but requires much cement, which may go beyond the farmers' affordability.

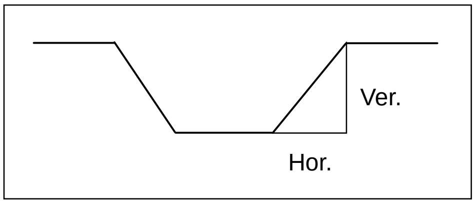
Considering medium scale irrigation water discharge, there are not so many lined, and in case of earth lining, leakages might happen and maintenance work is be required. Therefore, brick masonry should be used for main and secondary canal.

3) Canal Design

i) Cross-section and side-slopes
For earth canals, standard trapezoidal shape is commonly used. Required slope depends on the stability of the soil. Recommendable side slopes for different soils are given in **Table 2-30** below:

Table 2-30 Recommended Side Slopes for Different Types of Soils

Type of Soils	Recommendable Side Slope (Ver.) : (Hor.)
Clay	2 : 1
All other soils	2 : 1
Sand	1 : 1



Generally, rectangular cross section requires less excavation and less quantity of bricks. Considering safety of structure, it is recommendable to adopt trapezoid cross section. However, rectangular cross section may be adopted in case that the depth is less than 0.6 m, due to small soil pressure.

ii) Freeboard
Freeboard acts as a reserve depth in a canal to allow some variations in water flow. The freeboard is decided according to the planned discharge; more discharge, higher free board and less discharge, smaller free board. Irrigation schemes undertaken in this Guideline are medium-scale, therefore a minimum 10 cm to maximum of about 20 cm freeboard is recommended.
iii) Allowable flow velocity
The design velocity of canals must be determined within the limits of two factors; namely, 1) the minimum allowable velocity that causes neither accumulation of sediment of soils nor growth of waterweeds, and 2) the maximum allowable velocity that does not produce erosion of canal materials by the flow. Refer **Table 2-31** for Maximum allowable velocities of different types of canals.

The minimum allowable velocity: 0.45 – 0.90 m/sec

Within this range of mean velocity, soil sediments are not accumulated in a canal where the particle size of suspended sediment is not larger than silt. Waterweeds hindering the flow capacity of the canal do not grow when the mean velocity is more than 0.7 m/sec.

Table 2-31 Maximum Allowable Velocity

Type of Canal Material	Maximum Allowable Velocity, (m/s)	Type of Canal Material	Maximum Allowable Velocity, (m/s)
Sandy soil	0.4 - 0.6	Thin concrete (approx.10cm)	1.5 - 2.5
Sand-loam	0.5 - 0.7		
Clay-loam	0.6 - 0.9	Brick masonry with mortar filled	2.50
Clay	0.9 - 1.5		
Rock	1.0 - 2.0		

Table 2-32 Value of Roughness Coefficient

Materials and conditions of canals	Roughness Coefficient		
	Minimum value	Standard value	Maximum value
Concrete (cast-in-place flume, culvert, etc.)	0.012	0.015	0.016
Concrete (shotcrete)	0.016	0.019	0.023
Concrete (with precast flume, pipe, etc.)	0.012	0.014	0.016
Concrete (reinforced concrete pipe)	0.011	0.013	0.014
Concrete block masonry	0.014	0.016	0.017
Cement (mortar)	0.011	0.013	0.015
Asbestos cement pipe	0.011	0.013	0.014
Steel (locked bar or welded)	0.010	0.012	0.014
Steel (revet)	0.013	0.016	0.017
Smooth steel surface (not painted)	0.011	0.012	0.014
Smooth steel surface and pipe (painted)	0.012	0.013	0.017
Corrugated surface (steel sheet)	0.021	0.025	0.030
Cast iron (not painted)	0.011	0.014	0.016
Cast iron sheet and pipe (painted)	0.010	0.013	0.014
Chloride vinyl pipe		0.012	
Reinforced plastic		0.012	
Ceramic pipe	0.011	0.014	0.017
Earth lining		0.025	
Asphalt (smooth surface)		0.014	
Asphalt (rough stone)		0.017	
Masonry (rough stone wet masonry)	0.017	0.025	0.030
Masonry (rough stone dry masonry)	0.023	0.032	0.035
Wood (wooden gutter)	0.010	0.012	0.014
Wood (lined in thin layer, treated with creosote)	0.015	0.017	0.020
Rock tunnel with no lining on overall cross-sectional area	0.030	0.035	0.040
Rock tunnel with no lining except concrete placed on the bottom	0.020	0.025	0.030
Vegetation coverage (turfing)	0.030	0.04	0.050

Source: Engineering Manual for Irrigation and Drainage Canal Works, The Japanese Institute of Irrigation and Drainage 1987.

4) Canal slope (earth)

Steep canal slope creates erosion due to its high flow velocity though it. On the other hand, too gentle slope cause heavy silting in the canal and also enlarges canal section to accommodate the required flow. Canal slope depends on the difference between the elevation at intake and farmland. If the slope is too steep and the water velocity is too high, the slope should be made gentler by setting a drop. If the slope can not be made steeper, frequent maintenance of de-silting should be required.

5) Canal dimension (brick)

The minimum canal bed width should be 0.23m considering size of brick and maintenance work. Standard cross section of canal is shown in **Figure 2-18 and 2-19**.

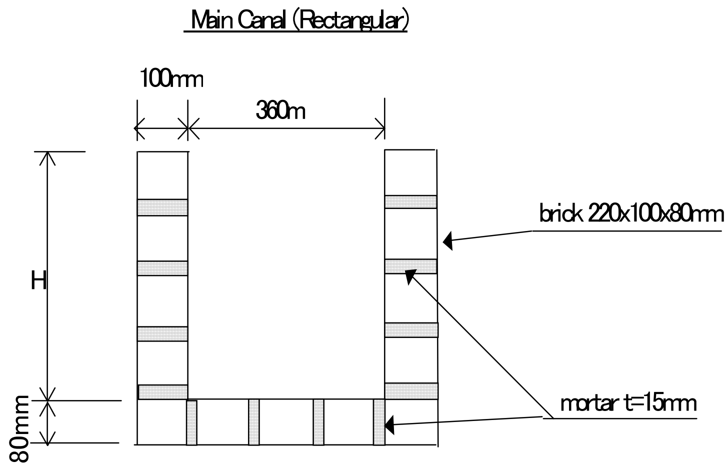


Figure 2-18 Standard Cross Section of Canal (B=0.34m, Rectangular)

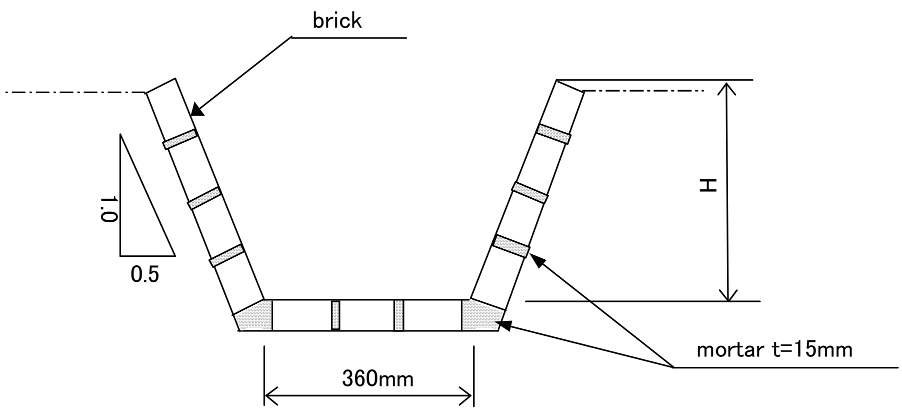


Figure 2-19 Standard Cross Section of Canal (B=0.34m, Trapezoid)

The recommended canal dimension; bottom width, water depth and total depth (= water depth + freeboard) for different design discharges and canal slopes and are presented in **Table 2-33** below:

Table 2-33 Recommended Canal Dimension for Various Discharges

Q=5 lit/s

Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.23	0.020	0.5 : 1.0	0.117	0.148	0.133	0.250
0.23	0.025	0.5 : 1.0	0.109	0.161	0.141	0.250
0.23	0.033	0.5 : 1.0	0.100	0.178	0.150	0.250
0.23	0.040	0.5 : 1.0	0.095	0.190	0.155	0.250
0.23	0.050	0.5 : 1.0	0.088	0.206	0.162	0.250
0.23	0.100	0.5 : 1.0	0.071	0.264	0.179	0.250
0.23	0.200	0.5 : 1.0	0.058	0.335	0.192	0.250
0.23	0.333	0.5 : 1.0	0.049	0.399	0.201	0.250
0.23	0.500	0.5 : 1.0	0.043	0.458	0.207	0.250

Q=5 lit/s

Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.23	0.020	0.0 : 1.0	0.152	0.143	0.148	0.300
0.23	0.025	0.0 : 1.0	0.139	0.156	0.111	0.250
0.23	0.033	0.0 : 1.0	0.125	0.174	0.125	0.250
0.23	0.040	0.0 : 1.0	0.116	0.187	0.134	0.250
0.23	0.050	0.0 : 1.0	0.107	0.203	0.143	0.250
0.23	0.100	0.0 : 1.0	0.083	0.262	0.167	0.250
0.23	0.200	0.0 : 1.0	0.065	0.335	0.185	0.250
0.23	0.333	0.0 : 1.0	0.054	0.400	0.196	0.250
0.23	0.500	0.0 : 1.0	0.047	0.459	0.203	0.250

Q=10 lit/s

Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.23	0.020	0.5 : 1.0	0.177	0.178	0.123	0.300
0.23	0.025	0.5 : 1.0	0.166	0.193	0.134	0.300
0.23	0.033	0.5 : 1.0	0.152	0.215	0.148	0.300
0.23	0.040	0.5 : 1.0	0.144	0.230	0.106	0.250
0.23	0.050	0.5 : 1.0	0.135	0.249	0.115	0.250
0.23	0.100	0.5 : 1.0	0.109	0.321	0.141	0.250
0.23	0.200	0.5 : 1.0	0.088	0.412	0.162	0.250
0.23	0.333	0.5 : 1.0	0.076	0.494	0.174	0.250
0.23	0.500	0.5 : 1.0	0.067	0.570	0.183	0.250

Q=10 lit/s

Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.34	0.020	0.0 : 1.0	0.172	0.171	0.128	0.300
0.34	0.025	0.0 : 1.0	0.158	0.186	0.142	0.300
0.34	0.033	0.0 : 1.0	0.142	0.207	0.158	0.300
0.23	0.040	0.0 : 1.0	0.199	0.218	0.101	0.300
0.23	0.050	0.0 : 1.0	0.182	0.239	0.118	0.300
0.23	0.100	0.0 : 1.0	0.139	0.313	0.111	0.250
0.23	0.200	0.0 : 1.0	0.107	0.406	0.143	0.250
0.23	0.333	0.0 : 1.0	0.089	0.490	0.161	0.250
0.23	0.500	0.0 : 1.0	0.077	0.567	0.173	0.250

Q=15 lit/s

Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.34	0.020	0.5 : 1.0	0.179	0.195	0.121	0.300
0.34	0.025	0.5 : 1.0	0.167	0.212	0.133	0.300
0.23	0.033	0.5 : 1.0	0.193	0.238	0.107	0.300
0.23	0.040	0.5 : 1.0	0.183	0.255	0.117	0.300
0.23	0.050	0.5 : 1.0	0.171	0.277	0.129	0.300
0.23	0.100	0.5 : 1.0	0.140	0.358	0.110	0.250
0.23	0.200	0.5 : 1.0	0.113	0.462	0.137	0.250
0.23	0.333	0.5 : 1.0	0.097	0.556	0.153	0.250
0.23	0.500	0.5 : 1.0	0.086	0.642	0.164	0.250

Q=15 lit/s

Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.34	0.020	0.0 : 1.0	0.234	0.188	0.116	0.350
0.34	0.025	0.0 : 1.0	0.215	0.206	0.135	0.350
0.34	0.033	0.0 : 1.0	0.192	0.230	0.108	0.300
0.34	0.040	0.0 : 1.0	0.179	0.246	0.121	0.300
0.34	0.050	0.0 : 1.0	0.165	0.267	0.135	0.300
0.23	0.100	0.0 : 1.0	0.191	0.341	0.109	0.300
0.23	0.200	0.0 : 1.0	0.145	0.448	0.105	0.250
0.23	0.333	0.0 : 1.0	0.120	0.545	0.130	0.250
0.23	0.500	0.0 : 1.0	0.103	0.634	0.147	0.250

Q = 20 lit/s

Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.34	0.020	0.5 : 1.0	0.213	0.211	0.137	0.350
0.34	0.025	0.5 : 1.0	0.199	0.229	0.151	0.350
0.34	0.033	0.5 : 1.0	0.182	0.254	0.118	0.300
0.34	0.040	0.5 : 1.0	0.173	0.272	0.127	0.300
0.34	0.050	0.5 : 1.0	0.161	0.295	0.139	0.300
0.23	0.100	0.5 : 1.0	0.166	0.386	0.134	0.300
0.23	0.200	0.5 : 1.0	0.135	0.499	0.115	0.250
0.23	0.333	0.5 : 1.0	0.116	0.602	0.134	0.250
0.23	0.500	0.5 : 1.0	0.102	0.697	0.148	0.250

Q = 20 lit/s

Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.34	0.020	0.0 : 1.0	0.294	0.200	0.106	0.400
0.34	0.025	0.0 : 1.0	0.269	0.219	0.131	0.400
0.34	0.033	0.0 : 1.0	0.240	0.245	0.110	0.350
0.34	0.040	0.0 : 1.0	0.224	0.263	0.126	0.350
0.34	0.050	0.0 : 1.0	0.205	0.287	0.145	0.350
0.34	0.100	0.0 : 1.0	0.158	0.373	0.142	0.300
0.23	0.200	0.0 : 1.0	0.182	0.477	0.118	0.300
0.23	0.333	0.0 : 1.0	0.149	0.583	0.101	0.250
0.23	0.500	0.0 : 1.0	0.128	0.681	0.122	0.250

Q = 30 lit/s

Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.34	0.020	0.5 : 1.0	0.270	0.234	0.130	0.400
0.34	0.025	0.5 : 1.0	0.253	0.254	0.147	0.400
0.34	0.033	0.5 : 1.0	0.233	0.283	0.117	0.350
0.34	0.040	0.5 : 1.0	0.220	0.303	0.130	0.350
0.34	0.050	0.5 : 1.0	0.206	0.329	0.144	0.350
0.23	0.100	0.5 : 1.0	0.210	0.427	0.140	0.350
0.23	0.200	0.5 : 1.0	0.171	0.554	0.129	0.300
0.23	0.333	0.5 : 1.0	0.147	0.670	0.103	0.250
0.23	0.500	0.5 : 1.0	0.131	0.778	0.119	0.250

Q = 30 lit/s

Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.45	0.020	0.0 : 1.0	0.297	0.225	0.153	0.450
0.45	0.025	0.0 : 1.0	0.272	0.245	0.128	0.400
0.34	0.033	0.0 : 1.0	0.332	0.266	0.118	0.450
0.34	0.040	0.0 : 1.0	0.308	0.286	0.142	0.450
0.34	0.050	0.0 : 1.0	0.282	0.313	0.118	0.400
0.34	0.100	0.0 : 1.0	0.215	0.411	0.135	0.350
0.34	0.200	0.0 : 1.0	0.165	0.535	0.135	0.300
0.23	0.333	0.0 : 1.0	0.206	0.635	0.144	0.350
0.23	0.500	0.0 : 1.0	0.175	0.746	0.125	0.300

Q = 40 lit/s

Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.34	0.020	0.5 : 1.0	0.319	0.251	0.131	0.450
0.34	0.025	0.5 : 1.0	0.299	0.273	0.151	0.450
0.34	0.033	0.5 : 1.0	0.275	0.304	0.125	0.400
0.34	0.040	0.5 : 1.0	0.261	0.326	0.139	0.400
0.34	0.050	0.5 : 1.0	0.244	0.354	0.156	0.400
0.23	0.100	0.5 : 1.0	0.247	0.458	0.103	0.350
0.23	0.200	0.5 : 1.0	0.203	0.595	0.147	0.350
0.23	0.333	0.5 : 1.0	0.175	0.721	0.125	0.300
0.23	0.500	0.5 : 1.0	0.155	0.839	0.145	0.300

Q = 40 lit/s

Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.45	0.020	0.0 : 1.0	0.373	0.239	0.127	0.500
0.45	0.025	0.0 : 1.0	0.341	0.261	0.109	0.450
0.34	0.033	0.0 : 1.0	0.421	0.279	0.129	0.550
0.34	0.040	0.0 : 1.0	0.390	0.301	0.110	0.500
0.34	0.050	0.0 : 1.0	0.356	0.331	0.144	0.500
0.34	0.100	0.0 : 1.0	0.269	0.438	0.131	0.400
0.34	0.200	0.0 : 1.0	0.205	0.574	0.145	0.350
0.23	0.333	0.0 : 1.0	0.260	0.669	0.140	0.400
0.23	0.500	0.0 : 1.0	0.220	0.790	0.130	0.350

Q = 50 lit/s

Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.34	0.020	0.5 : 1.0	0.362	0.265	0.138	0.500
0.34	0.025	0.5 : 1.0	0.340	0.288	0.110	0.450
0.34	0.033	0.5 : 1.0	0.313	0.321	0.137	0.450
0.34	0.040	0.5 : 1.0	0.297	0.344	0.103	0.400
0.34	0.050	0.5 : 1.0	0.279	0.374	0.121	0.400
0.23	0.100	0.5 : 1.0	0.280	0.483	0.120	0.400
0.23	0.200	0.5 : 1.0	0.230	0.629	0.120	0.350
0.23	0.333	0.5 : 1.0	0.199	0.763	0.151	0.350
0.23	0.500	0.5 : 1.0	0.177	0.888	0.123	0.300

Q = 50 lit/s

Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.45	0.020	0.0 : 1.0	0.446	0.249	0.104	0.550
0.45	0.025	0.0 : 1.0	0.407	0.273	0.143	0.550
0.45	0.033	0.0 : 1.0	0.363	0.306	0.137	0.500
0.45	0.040	0.0 : 1.0	0.338	0.329	0.162	0.500
0.45	0.050	0.0 : 1.0	0.309	0.359	0.141	0.450
0.34	0.100	0.0 : 1.0	0.322	0.457	0.128	0.450
0.23	0.200	0.0 : 1.0	0.244	0.603	0.106	0.350
0.23	0.333	0.0 : 1.0	0.200	0.735	0.150	0.350
0.23	0.500	0.0 : 1.0	0.172	0.857	0.128	0.300

Q = 60 lit/s

Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.34	0.020	0.5 : 1.0	0.401	0.277	0.149	0.550
0.34	0.025	0.5 : 1.0	0.377	0.301	0.123	0.500
0.34	0.033	0.5 : 1.0	0.348	0.336	0.102	0.450
0.34	0.040	0.5 : 1.0	0.330	0.360	0.120	0.450
0.34	0.050	0.5 : 1.0	0.310	0.392	0.140	0.450
0.34	0.100	0.5 : 1.0	0.253	0.508	0.147	0.400
0.34	0.200	0.5 : 1.0	0.206	0.657	0.144	0.350
0.23	0.333	0.5 : 1.0	0.221	0.798	0.129	0.350
0.23	0.500	0.5 : 1.0	0.197	0.929	0.103	0.300

Q = 60 lit/s

Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.56	0.020	0.0 : 1.0	0.403	0.266	0.147	0.550
0.45	0.025	0.0 : 1.0	0.473	0.282	0.127	0.600
0.45	0.033	0.0 : 1.0	0.420	0.317	0.130	0.550
0.45	0.040	0.0 : 1.0	0.391	0.341	0.109	0.500
0.45	0.050	0.0 : 1.0	0.357	0.373	0.143	0.500
0.34	0.100	0.0 : 1.0	0.374	0.472	0.126	0.500
0.34	0.200	0.0 : 1.0	0.282	0.626	0.118	0.400
0.34	0.333	0.0 : 1.0	0.230	0.766	0.120	0.350
0.34	0.500	0.0 : 1.0	0.197	0.896	0.103	0.300

Q = 70 lit/s

Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.45	0.020	0.5 : 1.0	0.379	0.289	0.121	0.500
0.45	0.025	0.5 : 1.0	0.355	0.314	0.145	0.500
0.34	0.033	0.5 : 1.0	0.379	0.349	0.121	0.500
0.34	0.040	0.5 : 1.0	0.360	0.374	0.140	0.500
0.34	0.050	0.5 : 1.0	0.338	0.407	0.112	0.450
0.34	0.100	0.5 : 1.0	0.277	0.528	0.123	0.400
0.34	0.200	0.5 : 1.0	0.226	0.684	0.124	0.350
0.23	0.333	0.5 : 1.0	0.241	0.828	0.109	0.350
0.23	0.500	0.5 : 1.0	0.215	0.965	0.135	0.350

Q = 70 lit/s

Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.56	0.020	0.0 : 1.0	0.455	0.275	0.145	0.600
0.56	0.025	0.0 : 1.0	0.416	0.300	0.134	0.550
0.45	0.033	0.0 : 1.0	0.477	0.326	0.123	0.600
0.45	0.040	0.0 : 1.0	0.442	0.352	0.108	0.550
0.45	0.050	0.0 : 1.0	0.404	0.385	0.146	0.550
0.34	0.100	0.0 : 1.0	0.425	0.485	0.125	0.550
0.34	0.200	0.0 : 1.0	0.319	0.645	0.131	0.450
0.34	0.333	0.0 : 1.0	0.260	0.792	0.140	0.400
0.34	0.500	0.0 : 1.0	0.222	0.928	0.128	0.350

Q = 80 lit/s

Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.45	0.020	0.5 : 1.0	0.409	0.299	0.141	0.550
0.45	0.025	0.5 : 1.0	0.384	0.325	0.116	0.500
0.45	0.033	0.5 : 1.0	0.353	0.362	0.147	0.500
0.34	0.040	0.5 : 1.0	0.388	0.386	0.112	0.500
0.34	0.050	0.5 : 1.0	0.365	0.420	0.135	0.500
0.34	0.100	0.5 : 1.0	0.299	0.546	0.101	0.400
0.34	0.200	0.5 : 1.0	0.244	0.708	0.156	0.400
0.23	0.333	0.5 : 1.0	0.260	0.855	0.140	0.400
0.23	0.500	0.5 : 1.0	0.232	0.997	0.118	0.350

Q = 80 lit/s

Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.67	0.020	0.0 : 1.0	0.415	0.287	0.135	0.550
0.56	0.025	0.0 : 1.0	0.463	0.309	0.137	0.600
0.56	0.033	0.0 : 1.0	0.413	0.346	0.137	0.550
0.45	0.040	0.0 : 1.0	0.494	0.360	0.106	0.600
0.45	0.050	0.0 : 1.0	0.450	0.395	0.150	0.600
0.45	0.100	0.0 : 1.0	0.341	0.522	0.109	0.450
0.45	0.200	0.0 : 1.0	0.260	0.683	0.140	0.400
0.34	0.333	0.0 : 1.0	0.289	0.814	0.111	0.400
0.34	0.500	0.0 : 1.0	0.246	0.956	0.104	0.350

Q = 90 lit/s

Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.45	0.020	0.5 : 1.0	0.438	0.307	0.112	0.550
0.45	0.025	0.5 : 1.0	0.411	0.334	0.139	0.550
0.45	0.033	0.5 : 1.0	0.378	0.372	0.122	0.500
0.45	0.040	0.5 : 1.0	0.359	0.399	0.141	0.500
0.34	0.050	0.5 : 1.0	0.389	0.432	0.111	0.500
0.34	0.100	0.5 : 1.0	0.320	0.562	0.130	0.450
0.34	0.200	0.5 : 1.0	0.262	0.729	0.138	0.400
0.23	0.333	0.5 : 1.0	0.278	0.879	0.122	0.400
0.23	0.500	0.5 : 1.0	0.248	1.026	0.102	0.350

Q = 90 lit/s

Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.67	0.020	0.0 : 1.0	0.455	0.295	0.145	0.600
0.67	0.025	0.0 : 1.0	0.417	0.322	0.133	0.550
0.56	0.033	0.0 : 1.0	0.453	0.354	0.147	0.600
0.56	0.040	0.0 : 1.0	0.422	0.381	0.128	0.550
0.45	0.050	0.0 : 1.0	0.496	0.403	0.104	0.600
0.45	0.100	0.0 : 1.0	0.374	0.534	0.126	0.500
0.34	0.200	0.0 : 1.0	0.392	0.675	0.108	0.500
0.34	0.333	0.0 : 1.0	0.318	0.832	0.132	0.450
0.34	0.500	0.0 : 1.0	0.270	0.980	0.130	0.400

Q=100 lit/s — Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.45	0.020	0.5 : 1.0	0.465	0.315	0.135	0.600
0.45	0.025	0.5 : 1.0	0.436	0.343	0.114	0.550
0.45	0.033	0.5 : 1.0	0.402	0.382	0.148	0.550
0.45	0.040	0.5 : 1.0	0.381	0.409	0.119	0.500
0.45	0.050	0.5 : 1.0	0.357	0.445	0.143	0.500
0.34	0.100	0.5 : 1.0	0.340	0.577	0.110	0.450
0.34	0.200	0.5 : 1.0	0.279	0.749	0.121	0.400
0.23	0.333	0.5 : 1.0	0.294	0.902	0.106	0.400
0.23	0.500	0.5 : 1.0	0.263	1.052	0.137	0.400

Q=100 lit/s — Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.67	0.020	0.0 : 1.0	0.494	0.302	0.106	0.600
0.67	0.025	0.0 : 1.0	0.453	0.330	0.147	0.600
0.56	0.033	0.0 : 1.0	0.493	0.362	0.107	0.600
0.56	0.040	0.0 : 1.0	0.459	0.389	0.141	0.600
0.56	0.050	0.0 : 1.0	0.420	0.425	0.130	0.550
0.45	0.100	0.0 : 1.0	0.407	0.545	0.143	0.550
0.34	0.200	0.0 : 1.0	0.428	0.686	0.122	0.550
0.34	0.333	0.0 : 1.0	0.347	0.849	0.103	0.450
0.34	0.500	0.0 : 1.0	0.294	1.000	0.106	0.400

Q=150 lit/s — Side Slope 0.5 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.56	0.020	0.5 : 1.0	0.523	0.349	0.127	0.650
0.56	0.025	0.5 : 1.0	0.490	0.380	0.110	0.600
0.56	0.033	0.5 : 1.0	0.451	0.423	0.149	0.600
0.45	0.040	0.5 : 1.0	0.481	0.452	0.119	0.600
0.45	0.050	0.5 : 1.0	0.451	0.492	0.149	0.600
0.45	0.100	0.5 : 1.0	0.370	0.639	0.130	0.500
0.34	0.200	0.5 : 1.0	0.352	0.827	0.148	0.500
0.34	0.333	0.5 : 1.0	0.304	1.003	0.146	0.450
0.34	0.500	0.5 : 1.0	0.270	1.169	0.130	0.400

Q=150 lit/s — Side Slope 0.0 : 1.0

Bed Width (m)	Canal Slope (%)	Side Slope Ver : Hor	Water Depth (m)	Velocity (m/s)	Freeboard (m)	Canal Depth (m)
0.89	0.020	0.0 : 1.0	0.500	0.337	0.100	0.600
0.89	0.025	0.0 : 1.0	0.460	0.367	0.140	0.600
0.78	0.033	0.0 : 1.0	0.472	0.408	0.128	0.600
0.78	0.040	0.0 : 1.0	0.440	0.437	0.110	0.550
0.67	0.050	0.0 : 1.0	0.474	0.472	0.126	0.600
0.56	0.100	0.0 : 1.0	0.440	0.609	0.110	0.550
0.45	0.200	0.0 : 1.0	0.427	0.780	0.173	0.600
0.34	0.333	0.0 : 1.0	0.487	0.907	0.113	0.600
0.34	0.500	0.0 : 1.0	0.410	1.076	0.140	0.550

6) Turnout

Turnouts are made to distribute water to secondary and tertiary canals. Turnouts are opened and closed following rotational irrigation schedule. Stop logs are recommended for closing turnout however sand bags or bricks and banana leaves are also acceptable. Interval of turnout depends on a number of factors and should lead water to secondary canal. They are mostly spaced at 40m to 60m.

7) Stream/Gully Crossing

Stream/Gully crossing should consist of brick made boxes and pipe. Boxes should be constructed at each side of stream or gully and connected with a pipe. It is possible to make stream/gully crossing with tree bark, logs, bamboo and plastic paper supported by logs but it should be removed during flood season. Therefore, adoption of stream/gully crossing made of bricks and pipe is recommendable for a medium scale irrigation scheme. The length of stream/gully crossing should be less than 6m considering the length and strength of pipe. If the length of stream/gully crossing exceeds 6m, it should be supported. Since the support should be enough strong and durable in order not to be washed away by a flash water, it is costly and requires technical consideration. The location of stream/gully crossing should be determined to make the length as shorter as possible (less than 6m). The flow capacity of pipes is shown **Table 2-34** below.

Table 2-34 Maximum Pipe Flow Quantity of Uniform Flow

Pipe Diameter (Nom. Size)	Gradient 1/300	Gradient 1/500
φ 100	3.9 lit/s	3.1 lit/s
φ 125	6.7 lit/s	5.2 lit/s
φ 150	9.6 lit/s	7.5 lit/s
φ 200	24.4 lit/s	18.9 lit/s
φ 225	32.3 lit/s	25.1 lit/s

8) Road Crossing

Road crossing should consist of brick made boxes and pipes. Boxes should be constructed at each side of the road and connected with pipes. Pipes should be installed at the depth of more than 30cm from the surface of the road. 30 cm soil cover is enough safe for gross weight 14 ton truck load. Pipes should be installed at the height of 10cm from canal bed, refer to the **Figure 2-20**. Siphon type is not recommended due to maintenance problems. It is recommended that the back filling material should be thoroughly compacted without destroying the canal walls.

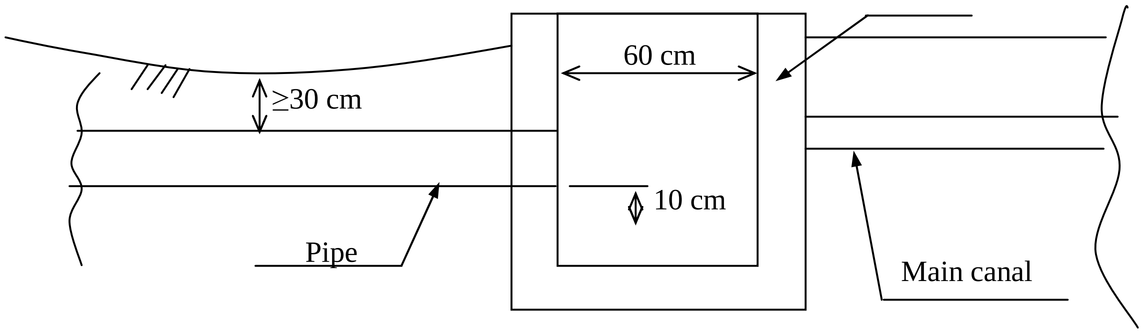


Figure 2-20 Standard Cross Section of Road Crossing

2.5 Rehabilitation Work Method

(1) Surface Preparation

Ground surfaces in areas to be excavated or where facilities are to be located should be cleared of all trees, bush, debris and surface vegetation. Stumps and roots larger than 50 mm in diameter should completely uproot and removed. Matted roots, surface vegetation should be removed regardless of size; they should completely remove with roots to a depth of not less than 10 cm below ground surface. All trees or groups of trees designated should be protected from damage from any construction operations.

(2) Excavation

Excavation should be planned and carried out to minimize adverse effects on the existing facilities and structures, as well as the vehicular and pedestrian traffic of and around the construction site.

Over excavation, below the depths indicated, should, unless otherwise be specified, refilled and compacted. If soft or unsuitable soil is found at the excavated depth, additional excavation should be carried out to depth and filled and compacted. Soil disturbed or weakened and soils deteriorated by exposure to weather should be excavated and excavated areas refilled and compacted.

Generally, all excavations should be kept free from water during construction. If soft or unsuitable soil is encountered after excavation to the designated bottom of the trench or structure, the ground should be excavated to a firm foundation level and filled over the excavated area with backfilling material.

(3) Replacement and Embankment

Material for the replacement and embankment should be placed in horizontal layers of uniform thickness over a width determined and in conformity with the lines, grades, sections, and dimensions. The layer of loose material other than rock should be not more than 30 cm thick. After adjustment of the moisture content, the loose material should be compacted.

(4) Stone Masonry

1) Material

i) Stone
Stone for Stone Masonry should consist of field stone or rough un-hewn quarry stone as nearly rectangular in section as is practical, including such stone or material observed being in use on the existing work. The stone should be sound, tough, durable, dense, resistant to the action of air and water, and suitable in all respects for the purpose intended. The size of the stone should be 10 cm minimum and 30 cm maximum.
ii) Sand
Sand for mortar should be river sand, free from silt, salt and other organic foreign matter.
iii) Water
Water for mortar should be clean and free from harmful matter, such as oil, salts, organic matter, or any material which may have a harmful effect on the mortar. Potable water (except for bacteriological limits and conditions) is suitable for the mixing of mortar under all conditions.
iv) Mortar mix
Standard mixing proportion of cement and mortar is as follows,
Ordinary Portland Cement 1 bucket of cement: 3 buckets of Sand
Mortar should be mixed uniformly with water to the proper consistency for spreading by trowel. Mortar which has been mixed with water for more than 45 minutes should not be used.

2) Construction

Excavation should be made to the required shape and depth, and should be compacted to a firm, even surface. All surpluses, soft and unsuitable material should be removed and replaced with suitable material which should be thoroughly compacted.

Stone should be washed with water before placing. Mortar should be pushed into the interstices of the stone within a short time after placing. The spaces between the stones are then filled with mortar. Sufficient mortar should be used to completely fill all voids, except that the face surface of the stone is left for exposition. The surface of stone masonry should be finished neatly and smoothly. After completion of Stone Masonry, it should be cured with water for more than 10 hours.

(5) Gabion

1) Material

The wire mesh should be made of galvanized steel having a minimum size of 2.7 mm (0.106 inch) diameter. The length and width of bamboo gabion should be less than one meter and the height less than 0.6 meter. The gabions should consist of hard rocks which are durable rock pieces that might not deteriorate when submerged in water or exposed to severe weather conditions. Rock pieces should be generally uniformly graded in sizes ranging from 100mm to 200mm. All Voids should be evenly distributed.

2) Construction

The wire mesh should be twisted to form hexagonal openings of uniform sizes. The maximum linear dimension of the mesh opening should not exceed 110 mm (4 ½ inches) and the area of mesh opening should not exceed 51.6 sq.cm (8 square inches). The mesh should then be fabricated non-raveled. Non-raveling is defined as the ability to resist pulling apart at any of the twists or connections forming the mesh when a single wire strand in a section is cut.

Gabion should be fabricated in such a manner that the side, ends, lid, and diaphragms can be assembled at the construction site into rectangular baskets of the specific sizes. Gabions should be of single unit construction, base, lids, ends, and sides should be either woven into a single unit or one edge of these members connected to the base section of the gabion in such a manner that the strength and flexibility at the point of connection is at least equal to that of the mesh.

The gabion should be equally divided by diaphragms, of the same mesh and gauge as the body of the gabions, into cells the length of which does not exceed the horizontal width. The gabion should be furnished with the necessary diaphragms secured in proper position on the base, such that no additional tying at this junction are necessary.

The gabions are then filled with stone carefully placed by hand to assure alignment and avoid bulges with a minimum of voids. Alternate placing of rock and connection wires should be performed until the gabion is filled. After a gabion has been filled, the lid should be bent over until it meets the sides and edges. The lid should then be secured to the sides, ends and diaphragms with the wire ties or connecting wire in the manner described for assembling.

The bamboo gabion should be fabricated at the site. Bamboo should be cut about 2cm in width. The space of vertical member should not be more than 10 cm. Horizontal member should be woven in and out the vertical member. The space of horizontal member should not be more than 3cm. Bottom member should be lattice arranged. The top of face should be woven with string or wire.

(6) Brick Masonry

1) Material

Brick for brick masonry should be sound, tough, durable, dense, resistant to the action of air and water, and suitable in all respects for the purpose intended. Standard size of the brick should be 10 cm x 8 cm x 22 cm. Standard mixing proportion of cement and mortar should be as follows;

Ordinary Portland Cement   1 bucket of Cement: 3 buckets of Sand

2) Construction

Brick should be laid straight. Thickness of joint mortar shall be 1 to 2 cm. The joint between the bricks should be filled with mortar completely and the surface of brick masonry finished neat and smooth.

(7) Safety and Environment

1) Safety

Reasonable precaution to protect persons or property from injury should be exercised and maximum care should also be put in place for people around them.

2) Environment

All necessary precautions should be taken to secure the efficient protection of all waterways against pollution, including spillage of oil which may be likely to cause injury to fish or plant life. Waste water from washing tools for mortar work such as mortar box, shovels, buckets and trowels should not be poured into a river directly.

2.6 Work Plan

(1) General

Construction plan is to establish that the way how the project is implemented safely and within the specified time and cost, and construction method and procedure. Construction work has different types, sizes, and locations and construction conditions are different from one to another. To execute these works in systematic and organized ways, the construction plan appropriate for each work needs to be prepared.

i) Based on design, work method is established.
ii) Based on design, quantity of required materials is calculated.
iii) Based on quantity and work method, required manpower is calculated.
iv) Based on quantity and manpower, construction cost is calculated.
v) Based on manpower, work schedule is drawn up.

(2) Bill of Quantity

Quantity of required materials should be calculated in accordance with drawing. Following items are calculated.

- Excavation
- Embankment
- Stone masonry
- Rubble stones
- Mortar
- Sand
- Cement
- Bricks
- Pipes
- Gabions
- Others

i) Excavation

Quantity of excavation is calculated in accordance with cross section.

Vex = (A1 + A2)/2 x L1 + (A2 + A3)/2 x L2 + ... + (An-1 +An)/2 x Ln

Vex: Excavation volume (m^3)

An: Cross sectional area of excavation at An (m)

Ln: Distance between An-1 and An (m)

or

Vex = A x D (m^3)

A: Excavation area (m^2)

D: Excavation depth (m)

ii) Embankment

Quantity of embankment shall be calculated in accordance with cross section.

Vem = (A1 + A2)/2 x L1 + (A2 + A3)/2 x L2 + ... + (An-1 +An)/2 x Ln

Vem: Embankment volume (m^3)

An: Cross sectional area of embankment at An (m)

Ln: Distance between An-1 and An (m)

iii) Stone masonry

Quantity of stone masonry is calculated in accordance with cross section.

iv) Rubble stone (stone masonry)

Quantity of rubble stone for stone masonry is calculated as follows

Vrs = Vsm x 1.08 (m^3)

1.08: coefficient of loss

Vrs: Volume of rubble stone (m^3)

Vsm: Volume of stone masonry (m^3)

v) Mortar for stone masonry

Quantity of mortar for stone masonry is calculated as follows

Vmo = Vsm x 0.5 x 1.1 (m^3)

Vmo: Volume of mortar for stone masonry (m^3)

Vsm: Volume of stone masonry (m^3)

0.5: coefficient of ratio

1.1: coefficient of loss

vi) Sand for mortar

Quantity of sand for mortar is calculated as follows

Vsa = Vmo x 0.8 (m^3)

Vsa: Volume of sand (m^3)

Vmo: Volume of mortar (m^3)

vii) Cement

Quantity of cement for mortar is calculated as follows

Vc = Vmo x 9.0 (bags)

Vc: Volume of cement (bags)

Vmo: Volume of mortar (m^3)

viii) Bricks

Quantity of bricks is calculated in accordance with drawings.

Standard quantity of brick canal is shown in next page.

ix) Gabions

Dimension of gabion wire net is 1.0m x 1.0m x 4.0m or 1.0m x 1.0m x 2.0m.

Dimension of bamboo gabion is be 0.6m (height) x 1.0m x 1.0m.

x) Rubble stones for gabion

Quantity of rubble stone for gabion is calculated as follows

Vrsg = Vga x 0.95 (m^3)

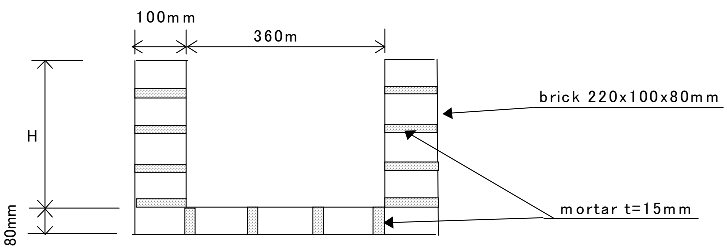
0.95: coefficient of ratio

Vrsg: Volume of rubble stone (m^3)

Vga: Volume of gabion (m^3)

Example of quantity calculation procedure is presented in **Figure 2-21** and **Figure 2-22** below and recording sheet is shown in **Table 2-35.**

Main Canal (Rectangular)



Standard size of brick shall be 220mm x 100mm x 80mm

(1) B = 0.36m, H = 0.38m wall 4 layers

Quantity per length of 2.35 m

Brick	13 x 10 = 130 pcs	
Mortar	0.015 x 0.1 x 2.35 x 4 x 2 + 0.015 x 0.08 x 2.35 x 4 + 0.015 x 0.08 x 0.1 x 13 x 10 = 0.05508 m^3	

Quantity per length of 1.0 m

Brick	130 / 2.35 x 1.1 = 60.85 pcs	1.1: coefficient of loss
Mortar	0.05508 / 2.35 x 1.3 = 0.0305 m^3	1.3 coefficient of loss

(2) B = 0.36m, H = 0.475 m wall 5 layers

Quantity per length of 2.35 m

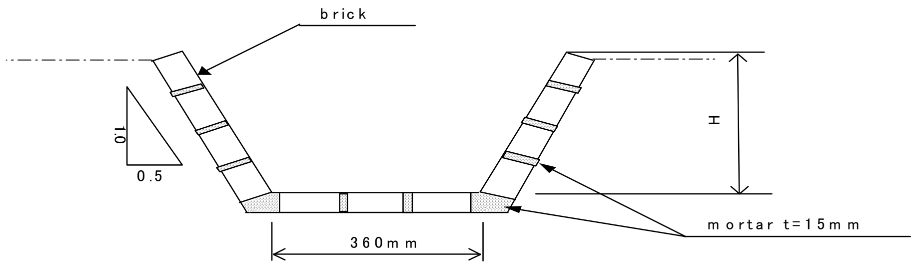
Brick	15 x 10 = 150 pcs	
Mortar	0.015 x 0.1 x 2.35 x 5 x 2 + 0.015 x 0.08 x 2.35 x 4 + 0.015 x 0.08 x 0.1 x 15 x 10 = 0.06453 m^3	

Quantity per length of 1.0 m

Brick	150 / 2.35 x 1.1 = 70.21 pcs	1.1: coefficient of loss
Mortar	0.06453 / 2.35 x 1.3 = 0.0357 m^3	1.3 coefficient of loss

<u>Figure 2-21 Main Canal Section (Rectangular) and Quantity Calculations</u>

Main Canal (Trapezoid)



(1) B = 0.36m, H = 0.39m wall 4 layers
Quantity per length of 2.35m
Brick Wall 10 pcs x 4 layers x 2 walls = 80 pcs
Base 10 pcs x 3 rows = 30 pcs
Total 80 + 30 = 110 pcs
Mortar Wall, Base 0.015 x 0.08 x 2.35 x 10 + 0.015 x 0.08 x 0.15 x 11x 10 = 0.048 m^3
Corner (0.08 x 0.08 x tan(31.72°) x 1/2 x 2 x 2) x 2.35 = 0.0186 m^3
Total 0.048 + 0.0186 = 0.0666 m^3 per 1m 0.0666 / 2.35 = 0.0283 m^3
Quantity per length of 1.0m
Brick 110 / 2.35 x 1.1 = 51.49 pcs
Mortar 0.0666 / 2.35 x 1.3 = 0.0368 m^3

(2) B = 0.36m, H = 0.50m wall 5 layers
Quantity per length of 2.35m
Brick Wall 10 pcs x 5 layers x 2 walls = 100 pcs
Base 10 pcs x 3 rows = 30 pcs
Total 100 + 30 = 130 pcs
Mortar Wall, Base 0.015 x 0.08 x 2.35 x 12 + 0.015 x 0.08 x 0.11 x 13 x 10 = 0.051 m^3
Corner (0.08 x 0.08 x tan(31.72°) x 1/2 x 2 x 2) x 2.35 = 0.0186 m^3
Total 0.051 + 0.0186 = 0.0696 m^3
Quantity per length of 1.0m
Brick 130 / 2.35 x 1.1 = 60.85 pcs
Mortar 0.0696 / 2.35 x 1.3 = 0.0385 m^3

(3) B = 0.36m, H = 0.62m wall 6 layers
Quantity per length of 2.35m
Brick Wall 10 pcs x 6 layers x 2 walls = 120 pcs
Base 10 pcs x 3 rows = 30 pcs
Total 120 + 30 = 150 pcs
Mortar Wall, Base 0.015 x 0.08 x 2.35 x 14 + 0.015 x 0.08 x 0.11 x 15 x 10 = 0.0593 m^3
Corner (0.08 x 0.08 x tan(31.72°) x 1/2 x 2 x 2) x 2.35 = 0.0186 m^3
Total 0.0593 + 0.0186 = 0.0779 m^3
Quantity per length of 1.0m
Brick 150 / 2.35 x 1.1 = 70.21 pcs
Mortar 0.0779 / 2.35 x 1.3 = 0.0431 m^3

Figure 2-22 Main Canal Section (Trapezoidal) and Quantity Calculation

Table 2-35 Example of Quantity Calculation Sheet

Site:

No.	Item	Specifoication/ Quality	calculation	Amount	Unit	Remarks
1	Weir	Stone Masonry	standard cross section			
			A1 = (0.6 + 1.9) x 1/2 x 1.3 + 1.9 x 0.5 = 2.575 m^2			
			end cross section			
			A2 = (0.6 + 0.9) x 1/2 x 0.3 = 0.225 m^2			
			V1 = 2.575 x 7.5 = 19.31 m^3			
			V2 = (2.575 + 0.225) x 1/2 x (2.0 + 3.0) = 7.00 m^3			
			V = 19.31 + 7.0 = 26.31			
		rubble stone	26.31 x 1.08 = 28.41m^3	28.4	m^3	
		mortar	26.31 x 0.5 x 1.1 =14.47 m^3			
		sand	14.47 x 0.8 = 11.58 m^3	11.6	m^3	
		cement	14.47 x 450 kg / 50 kg = 130.23 bag	131.0	bag	
		gabion		17.0	pc	
		rubble stone	1.0 x 1.0 x 2.0 x 0.95 x 15 =28.5 m^3	28.5	m^3	
2	Intake	Stone Masonry	A1 = (1.24 + 2.64) x 1/2 x 1.4 = 2.72 m^2			
			A2 = (1.0 + 2.2) x 1/2 x 1.2 = 1.92 m^2			
			V1 = (2.72-1.92) x (1.0 + 0.6 + 1.2 + 1.0) = 3.04 m^3			
			V2 = 1.92 x 0.6 = 1.15 m^3			
			V3 = 1.92 x 1/2 x 1.2 = 1.15 m^3			
			V = 3.04 + 1.15 + 1.15 = 5.34 m^3			
		rubble stone	5.34 x 1.08 = 5.77 m^3	5.8	m^3	
		mortar	5.34 x 0.5 x 1.1 = 2.94 m^3			
		sand	2.94 x 0.8 = 2.35 m^3	2.4	m^3	
		cement	2.94 x 450 kg / 50 kg = 26.46 bag	26.0	bag	
		PVC φ150		3.6	m	

Box

No.	Item	Specifoication /Quality	calculation	Amount	Unit	Remarks
1	Discharge Box	1.0m x 1.0m x 0.855m (Depth) wall 9 layers				
	Brick	wall	0.215 x 0.855 x (1.43 x 2 + 1.0 x 2) = 0.893 m^3			
		base	1.43 x 1.43 x 0.175 = 0.358 m^3			
		opening	not considered			
		total	0.893 + 0.358 = 1.251 m^3			
			1.251 / (0.235 x 0.115 x 0.095) x 1.1= 536.00 pc	536.0	pc	
	Mortar	wall	0.015 x 0.215 x (1.43 x 2 + 1.0 x 2) x 9 = 0.141 m^3			
			0.015 x 0.215 x (0.08 x 9) x ((1.43 x 2 +1.0 x 2) / 0.235) = 0.048 m^3			
		base	0.015 x (1.43 x 1.43 + 0.175 x (1.43 / 0.235) + 0.175 x (1.43 / 0.115)) = 0.079 m^3			
		opening	not considered			
		inside plastering	1.0 x 1.0 x 0.8 x 0.015 = 0.012 m^3			
		total	(0.141 + 0.048 + 0.079 + 0.012) x 1.3 = 0.364 m^3			
		sand	0.364 x 0.8 = 0.291 m^3	0.291	m^3	
		cement	0.364 x 450kg / 50kg = 3.276 bag	3.276	bag	
2	Box	0.6m x 0.6m x 0.475m (Depth) wall 5 layers				
	Brick	wall	0.215 x 0.475 x (1.03 x 2 + 0.6 x 2) = 0.333 m^3			
		base	1.03 x 1.03 x 0.175 = 0.186 m^3			
		opening	not considered			
		total	0.333 + 0.186 = 0.519 m^3			
			0.519 / (0.235 x 0.115 x 0.095) x 1.1= 222.37 pc	223.0	pc	
	Mortar	wall	0.015 x 0.215 x (1.03 x 2 + 0.6 x 2) x 5 = 0.052 m^3			
			0.015 x 0.215 x (0.08 x 5) x ((1.03 x 2 +0.6 x 2) / 0.235) = 0.018 m^3			
		base	0.015 x (1.03 x 1.03 + 0.175 x (1.03 / 0.235) + 0.175 x (1.03 / 0.115)) = 0.051 m^3			
		opening	not considered			
		inside plastering	0.6 x 0.6 x 0.475 x 0.015 = 0.003 m^3			
		total	(0052 + 0.018 + 0.051 + 0.003) x 1.3 = 0.161 m^3			
		sand	0.161 x 0.8 = 0.129 m^3	0.129	m^3	
		cement	0.161 x 450kg / 50kg = 1.449 bag	1.449	bag	

(3) Man Power and Tools Planning

Standard of required manpower, material and tools for each work is estimated as **Table 2-36**. These were established.

(4) Construction Cost

Construction cost is calculated based on bill of quantity and man power. Example of cost calculation sheet is shown in **Table 2-37**.

(5) Work Schedule

Based on quantity and required manpower for each item, construction period for each item is estimated. If the available labor per day is enough, putting large manpower into the work, shorten the construction period is shortened. Example of manpower planning is shown in the Table 2-32. Based on this man power planning, work progress schedule is drawn up. If man power is enough, work items can be executed simultaneously. Example of work progress schedule is shown in the **Figure 2-23**.

Table 2-36 Standards of Required Manpower, Materials and Tools

Labor Material and Tools

Item	name	specification, quality, shape	quantity	unit			remarks
1－1	Mortar per 1m^3		0.89m^3/day/1set				
	Material						
	Cement	Ordinary Portland	9.00	bags			450kg
	Sand	River sand	0.80	m^3			1.0 x 0.8
	Material Total						
	Labor						
	Mortar mixing	unskilled labor	2.25	man			2 x 9 / 8
	Helper	unskilled labor	4.50	man			4 x 9 / 8
	Labor Total		6.75	man			
	Tools (Daily)						
	Shovel		2.00	pcs			
	Bucket	20 lit	2.00	pcs			
	Wheelbarrow		1.00	pc			
	Mortar box		1.00	pc			
1－2	Mortar per 0.89m^3 / day/ 1 set						
	Material						
	Cement	Ordinary Portland	8.00	bags			400kg
	Sand	River sand	0.71	m^3			0.89 x 0.8
	Material Total						
	Labor						
	Mortar mixing	unskilled labor	2.00	man			
	Helper	unskilled labor	4.00	man			
	Labor Total		6.00	man			
	Tools (Daily)						
	Shovel		2.00	pcs			
	Bucket	20 lit	2.00	pcs			
	Wheelbarrow		1.00	pc			
	Mortar box		1.00	pc			
2－1	Construction of brick canal rectangular W=0.36m, D=0.38m wall 4 layers						
	12m / day / 1 set						
	Material						
	Bricks		730.20	pcs			60.85 x 12
	Mortar	1:3	0.37	m^3			0.031 x 12
	Material Total						
	Labor/day						
	Foreman		1.00	man			
	Mortar mixing	unskilled labor	4.00	man			1 day
	Excavation	unskilled labor	2.00	man			shaping
	Brick laying	skilled labor	1.00	man			
		unskilled labor	3.00	man			
	Helper	unskilled labor	4.00	man			
	Total labor		15.00	man			
	Tools (Daily)						
	Shovel		2.00	pcs			
	Bucket	20 lit	4.00	pcs			
	Wheelbarrow		3.00	pcs			
	Mortar box		1.00	pc			
	Trowel		4.00	pcs			
	Drum		1.00	pc			
	Hoe		2.00	pcs			
	Line level		1.00	pc			
	String		1.00	roll			
	Brick bolster		1.00	pc			
	Builder's level		1.00	pc			
	Measuring tape		1.00	pc			
	Peg						
2－2	Construction of brick canal rectangular W=0.36m, D=0.475m wall 5 layers						
	10.4m / day / 1 set						
	Material						
	Bricks		730.18	pcs			70.21 x 10.4
	Mortar	1:3	0.37	m^3			0.036 x 10.4
	Material Total						
	Labor/day						
	The same as 2－1						
	Tools						
	The same as 2－1						
3－1	Construction of Brick canal trapezoid W=0.36m, D=0.39m wall 4 layers						
	14.2m / day / 1 set						
	Bricks		731.16	pcs			51.49 x 14.2
	Mortar	1:3	0.53	m^3			0.037 x 14.2
	Material Total						
	Labor/day						
	The same as 2－1						
	Tools						
	The same as 2－1						
3－2	Construction of brick canal trapezoid W=0.36m, D=0.50m wall 5 layers						
	12m / day / 1 set						
	Material						
	Bricks		730.20	pcs			60.85 x 12
	Mortar	1:3	0.47	m^3			0.039 x 12
	Material Total						
	Labor/day						
	The same as 2－1						
	Tools						
	The same as 2－1						

Item	name	specification, quality, shape	quantity	unit			remarks
3-3	Construction of brick canal trapezoid W=0.36m, D=0.62m wall 6 layers						
	10.4m / day / 1 set						
	Material						
	Bricks		730.18	pcs			70.21 x 10.4
	Mortar	1:3	0.45	m^3			0.043 x 10.4
	Material Total						
	Labor/day						
	The same as 2-1						
	Tools						
	The same as 2-1						
4-1	Construction of discharge box 1000mm x 1000mm x 855mm (Depth) wall 9 layers						
	1 location / day / 1 set						
	Bricks		536.00	pcs			
	Mortar	1:3	0.36	m^3			
	Material Total						
	Labor/location 1location / 1 day						
	Foreman		1.00	man			
	Mortar mixing	unskilled labor	4.00	man			
	Excavation	unskilled labor	1.00	man			
	Brick laying	skilled labor	1.00	man			
		unskilled labor	2.00	man			
	Helper	unskilled labor	2.00	man			
	Total labor		11.00	man			
	Tools (Daily)						
	Shovel		1.00	pcs			
	Bucket	20 lit	3.00	pcs			
	Wheel barrow		2.00	pc			
	Mortar box		1.00	pc			
	Trowel		2.00	pcs			
	Drum		1.00	pc			
	Hoe		1.00	pc			
	Brick bolster		1.00	pc			
	Builder's level		1.00	pc			
	Measuring tape		1.00	pc			
	Peg						
4-2	Box	600mm x 600mm x 475mm (Depth) wall 5 layers					
	Bricks		223.00	pcs			
	Mortar	1:3	0.16	m^3			
	Material Total						
	Labor/location 3locations / 1 day						
	Foreman		0.33	man			
	Mortar mixing	unskilled labor	2.00	man			
	Excavation	unskilled labor	0.33	man			
	Brick laying	skilled labor	0.33	man			
		unskilled labor	0.67	man			

Item	name	specification, quality, shape	quantity	unit			remarks
	Helper	unskilled labor	0.67	man			
	Total labor		4.33	man			
	Tools (Daily)						
	Shovel		1.00	pcs			
	Bucket	20 lit	2.00	pcs			
	Wheel barrow		1.00	pc			
	Mortar box		1.00	pc			
	Trowel		2.00	pcs			
	Drum		1.00	pc			
	Hoe		1.00	pc			
	Brick bolster		1.00	pc			
	Builder's level		1.00	pc			
	Measuring tape		1.00	pc			
	Peg						
5	Excavation (by hand)	per 10m^3					
	Labor						
	unskilled labor		7.80	man			
	Tools						
	Shovel		3.00	pcs			
	Pickaxe		2.00	pcs			
	Hoe		2.80	pcs			
	String		1.00	roll			
	Peg						
6	Hauling excavated material per 1.0 m^3 by wheel barrow						
	Labor						
	unskilled labor	～ 20m	0.02	man			
	Wheel barrow	20～ 40m	0.06	man			
		40～ 60m	0.14	man			
		60～ 80m	0.24	man			
		80～ 100m	0.34	man			
		100～ 120m	0.44	man			
		120～ 140m	0.56	man			
		140～ 160m	0.66	man			
		160～ 180m	0.78	man			
		180～ 200m	0.90	man			
		one way distance					
7	Embankment (by hand)	per 10m^3					
	unskilled labor		7.60	man			
	Tools						
	Shovel		2.00	pcs			
	Hoe		3.60	pcs			
	Rammer		2.00	pcs			
	String		1.00	roll			
	Peg						

Item	name	specification, quality, shape	quantity	unit			remarks
8	Finishing slope (cut earth) per 100m^2						
	Labor						
	Foreman		1.40	man			
	Unskilled labor		11.80	man			
	Total labor		13.20	man			
	Tools						
	Shovel		4.00	pcs			
	Hoe		7.80	pcs			
	String		1.00	roll			
9	Finishing slope (embankment) per 100m^2						
	Labor						
	Foreman		1.60	man			
	Unskilled labor		25.80	man			
	Total labor		27.40	man			
	Tools						
	Shovel		4.00	pcs			
	Hoe		21.80	pcs			
	String		1.00	roll			
10	Stone masonry	per 1m^3					
	Material						
	Rubble stone		1.08	m^3			
	Mortar		0.55	m^3			
	Total material						
	Labor (not include mortar mixing)						
	Foreman		0.30	man			
	Skilled labor		0.60	man			
	Unskilled labor		3.60	man			
	Total labor		4.50	man			
	Tools (Daily, not include mortar mixing)						
	Bucket	20 lit	4.00	pcs			
	Wheelbarrow		4.00	pc			
	Trowel		4.00	pcs			
	Builder's level		1.00	pc			
	Measuring tape		1.00	pc			
	Peg						
11-1	Gabion work per piece	2.0m x 1.0m x 1.0m					
	Material						
	Rubble stone		1.90	m^3			2.0 x 0.95
	Gabion wire net		1.00	pc			
	Steel wire						
	Total material						

Item	name	specification, quality, shape	quantity	unit			remarks
	Labor						
	Foreman		0.13	man			
	Skilled labor		0.25	man			
	Unskilled labor		3.50	man			
	Total labor		3.88	man			
	Tools (Daily)						
	Wheelbarrow		2.00	pcs			
	Bucket		2.00	pcs			
	Plier		2.00	pcs			
	Builder's level		1.00	pc			
	Measuring tape		1.00	pc			
11-2	Gabion work per piece	2.0m x 1.0m x 0.5m					
	Material						
	Rubble stone		0.95	m^3			
	Gabion wire net		1.00	pc			
	Total material						
	Labor						
	Foreman		0.10	man			
	Skilled labor		0.20	man			
	Unskilled labor		2.00	man			
	Total labor		2.30	man			
	Tools (Daily)						
	The same as 11-1						
12	Discharge Pipe installation per 100m						
	Material						
	PVC pipe	class 6	16.7	pc			
	Foreman		0.50	man			
	Unskilled labor		7.50	man			
	Total labor		8.00	man			
13	Gathering stones	per 10m^3 distance 50m					
	Unskilled labor		15.00	man			
	Tools (daily)						
	Wheelbarrow		7.00	pcs			
	14 lbs hammer		4.00	pcs			
	4 lbs hammer		2.00	pcs			
	Chisel		2.00	pcs			
14	Tractor trailer loading and unloading						
	4 m^3 / 1 trip, 4 trips / day = 12 m^3 / day						
	unskilled labor		15.00	man			

Table 2-37 Example of Cost Calculation Sheet

Cost Estimation — Name of the Site: Example

No.	Item	Specification/Quality	Quantity	Unit	Unit Price MK	Price MK	Remarks
1	Preparation Work						
	Site clearing	unskilled labor	15.0	m・d	0.0	0.0	1day
	Gathering stones	unskilled labor	94.8	man	0.0	0.0	63.8/10x15
	Gathering sand	unskilled labor	37.8	man	0.0	0.0	25.2/10x15
	labor total					0.0	
2	Stone Masonry Weir	V=	40.0	m^3			
	rubble stone		43.2	m^3	0.0	0.0	40 x 1.08
	sand		17.6	m^3	0.0	0.0	40 x 0.5 x 1.1 x 0.8
	cement	ordinary portland	198.0	bag	2,500.0	495,000.0	40 x 0.5 x 1.1 x 9
	material total					495,000.0	
	excavation	unskilled labor	7.8	man	0.0	0.0	10m^3
	mortar mixing	unskilled labor	132.0	man	0.0	0.0	40 x 0.5 x 1.1 x 6
	stone masonry	foreman	12.0	man	0.0	0.0	0.3 x 40
		skilled labor	24.0	man	300.0	7,200.0	0.6 x 40
		unskilled labor	144.0	man	0.0	7,200.0	3.6 x 40
	labor total						
3	Intake	V=	5.0	m^3			
	rubble stone		5.4	m^3	0.0	0.0	5.0 x 1.08
	sand		2.2	m^3	0.0	0.0	5 x 0.5 x 1.1 x 0.8
	cement	ordinary portland	24.8	bag	2,500.0	61,875.0	5 x 0.5 x 1.1 x 9
	PVC	φ =140	1.0	pc	3,000.0	3,000.0	6m
	material total					64,875.0	
	excavation	unskilled labor	1.6	man	0.0	0.0	2m^3
	mortar mixing	unskilled labor	16.5	man	0.0	0.0	5 x 0.5 x 1.1 x 6
	stone masonry	foreman	1.5	man	0.0	0.0	0.3 x 5.0
		skilled labor	3.0	man	300.0	900.0	0.6 x 5.0
		unskilled labor	18.0	man	0.0	900.0	3.6 x 5.0
	labor total					1,800.0	
4	Main Canal Rectangular	W=0.36 D=0.38	300.0	m			
	bricks		18,255.0	pcs	1.5	27,382.5	730.2x300/12
	sand		7.4	m^3	0.0	0.0	0.37x300/12x0.5
	cement	ordinary portland	83.3	bag	2,500.0	27,382.5	0.37x300/12x9
	material total					54,765.0	
	excavation	unskilled labor	9.6	man	0.0	0.0	75m^3/7.8
	mortar mixing	unskilled labor	100.0	man	0.0	0.0	4x300/12
	brick laying	skilled labor	25.0	man	300.0	7,500.0	1x300/12
		unskilled labor	225.0	man	0.0	7,500.0	9*300/12
	labor total					15,000.0	
5	Gully Crossing	Box 600 x 600 x 475	3.0	pcs			
	bricks		669.0	pcs	1.5	1,003.5	223.0x3
	sand		0.4	m^3	0.0	0.0	0.16x0.8x3
	cement		4.3	bag	2,500.0	10,800.0	0.16x3x9
	PVC pipe	φ 140	3.0	pc	4,220.0	11,803.5	6m
	material total					23,607.0	

Cost Estimation — Name of the Site: Example

No.	Item	Specification/Quality	Quantity	Unit	Unit Price MK	Price MK	Remarks
	excavation	unskilled labor	1.0	man	0.0	0.0	0.33x3
	mortar mixing	unskilled labor	6.0	man	0.0	0.0	2.0x3
	brick laying	foreman	1.0	man	0.0	0.0	0.33x3
		skilled labor	1.0	man	300.0	300.0	0.33x3
		unskilled labor	2.0	man	0.0	300.0	0.67x3
	labor total					600.0	
6	Gabion Work						
	gabion	2.0 x 1.0 x 1.0	8.0	pcs	11000.0	88,000.0	
	rubble stone		15.2	m^3	0.0	0.0	2.0x0.95x8
	steel wire		2.0	kg	1250.0	2,500.0	
	material total					90,500.0	
	gabion work	foreman	1.0	man	0.0	0.0	0.13x8
		skilled labor	2.0	man	300.0	600.0	0.25x8
		unskilled labor	28.0	man	0.0	0.0	3.5x8
	labor total					600.0	
7	Fuel	diesel	50.0	lit	190.0	9500.0	
8	Others						
	Total Material Cost					921,066.0	
	rubble stone		63.8	m^3	0.0	0.0	
	sand		27.6	m^3	0.0	0.0	
	cement	ordinary portland	310.3	bag	2,500.0	775,800.0	
	bricks		18,924.0	pcs	1.5	28,386.0	
	gabion		8.0	pcs	11,000.0	88,000.0	
	steel wire		2.0	kg	1,250.0	2,500.0	
	PVC pipe	φ 140 class6	4.0	pcs	4,220.0	16,880.0	
	fuel	diesel	50.0	lit	190.0	9,500.0	
	Total Labor Cost					16,500.0	
	foreman	15.5		man	0.0	0.0	AEDO
	skilled labor	55.0		man	300.0	16,500.0	if employed
	unskilled labor	839.1		man	0.0	0.0	Farmers
	Total Construction Cost					937,566.0	

Table 2-38 Example of Manpower Planning

Manpower Planning Name of the Site: Example

No.	Item	Specification/ Quality	Quantity	Unit	period	day	Remarks
	Available labor						
	skilled labor	2 man / day					
	unskilled labor	20 man / day					
1	Preparation Work						
	Site clearing	unskilled labor	15.0	man・day	1.0	day	15man/day
	Gathering stones	unskilled labor	94.8	man・day	5.0	day	20man/day
	Gathering sand	unskilled labor	37.8	man・day	3.0	day	15man/day
	total				9.0	day	
2	Stone Masonry Weir						
	excavation	unskilled labor	7.8	man・day	1.0	day	8man/day
	mortar mixing	unskilled labor	132.0	man・day			6man/day
	stone masonry	foreman	12.0	man・day	22.0	day	1man/day
		skilled labor	24.0	man・day			2man/day
		unskilled labor	144.0	man・day			8man/day
	total				23.0	day	
3	Intake						
	excavation	unskilled labor	1.6	man・day	1.0	day	2man/day
	mortar mixing	unskilled labor	16.5	man・day			6man/day
	stone masonry	foreman	1.5	man・day	3.0	day	1man/day
		skilled labor	3.0	man・day			1man/day
		unskilled labor	18.0	man・day			6man/day
	total				4.0	day	
4	Main Canal Rectangular	W=0.36 D=0.38	300.0	m			
	excavation	unskilled labor	9.6	man・day	1.0	day	10ma/day
	mortar mixing	unskilled labor	100.0	man・day			4man/day
	brick laying	skilled labor	25.0	man・day	25.0	day	1man/day
		unskilled labor	225.0	man・day			9man/day
	total				26.0	day	
5	Gully Crossing	Box 600 x 600 x 475	3.0	pcs			
	excavation	unskilled labor	1.0	man・day			1man/day
	mortar mixing	unskilled labor	6.0	man・day			6man/day
	brick laying	foreman	1.0	man・day	1.0	day	1man/day
		skilled labor	1.0	man・day			1man/day
		unskilled labor	2.0	man・day			2man/day
	total				1.0	day	
6	Gabion Work	2.0x1.0x1.0	8pcs				
	gabion work	foreman	1.0	man・day			1man/day
		skilled labor	2.0	man・day	2.0	day	1man/day
		unskilled labor	28.0	man・day			14man/day
	total				2.0	day	

Name of the Site

WORK PROGRESS SCHEDULE

Item No.	Work Description	Quantity		Period	
1	Preparation Work			9.0	day
1-1	Site clearing	1.0	set	1.0	day
1-2	Gathering stones	63.8	m^3	5.0	day
1-3	Gathering sand	25.2	m^3	3.0	day
2	Construction of Stone Masonry Weir			23.0	day
2-1	Excavation	10.0	m^3	1.0	day
2-2	Stone Masonry Work	40.0	m^3	22.0	day
3	Construction of Intake			4.0	day
3-1	Excavation	2.0	m^3	1.0	day
3-2	Stone Masonry Work	5.0	m^3	3.0	day
4	Construction of Main Canal			26.0	
4-1	Excavation	75.0	m^3	1.0	day
4-2	Brick Work	18255.0	pcs	25.0	day
5	Construction of Gully Crossing			1.0	day
5-1	Excavation		m^3	1.0	day
5-2	Brick Work	669.0	pcs	1.0	day
6	Installation of Gabion			2.0	day
6-1	Gabion Work 2.0 x 1.0 x 1.0	8.0	pcs	2.0	day

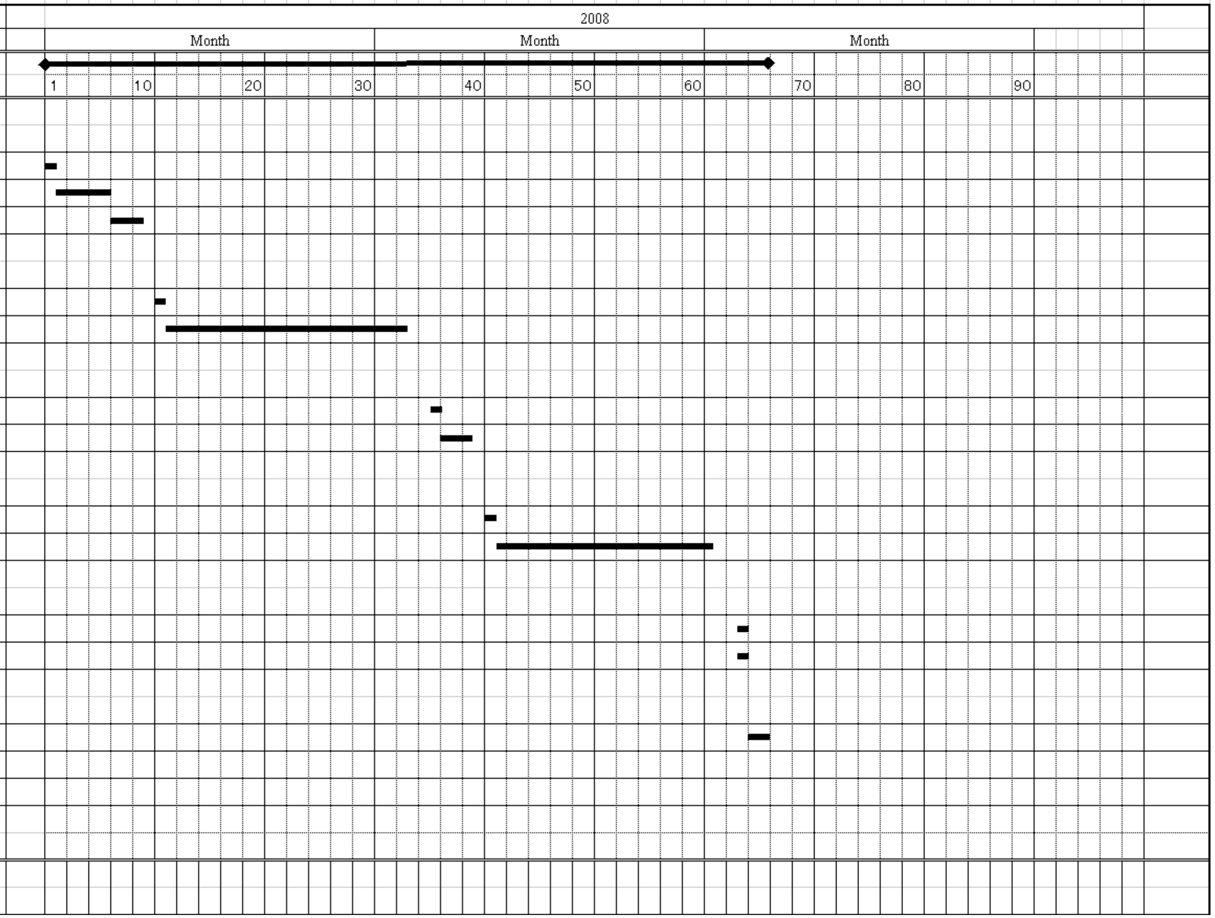


Figure 2-23 Example of Work Progress Schedule.

CHAPTER 3 O&M OF IRRIGATION FACILITIES

3.1 River Diversion Weir

As per fixed type weir of stone masonry or gabion, no routine maintenance work is usually required. Inspection around the weir should be carried out periodically and after every flood and every year before starting dry season irrigation. Following items should be inspected,

- Damaged part of stone masonry.
- Damaged part of gabion.
- Scouring at downstream of the weir.
- Sediment at upstream.
- Scouring at both side abutments.

Damaged part of stone masonry gabion should be repaired with mortar and damaged part of gabion should also be considered for rehabilitation. Scoured part at downstream of the weir should be protected by gabion or stone pitching. Scoured side abutment should be replaced with stone masonry or gabion, or reinforced with gabion or sand bags. In the case that sediment accumulated to inflow to canal, it should be removed. Maintenance check list is shown in the **Table 3-1.**

3.2 Water Impounding Dam

Inspection around the dam should be carried out periodically and after every flood and every year before starting dry season irrigation. Following things are inspected.

- Water seepage from embankment
- Erosion, collapse and/or cracks of embankment
- Damage and/or crack of spillway stone masonry
- Scouring at both side of spillway
- Sediment around intake facility
- Function of intake and outlet gates, valves

Maintenance check list is shown in the **Table 3-1**.

3.3 Motorized Pump

Mechanical equipment is affected by, increased wear, deformation, or deterioration during operation, low performance shortened life by the occurrence of severe oil leaks and moisture, weather conditions, artificial obstacles, etc. As these items cause problems, it is necessary that careful periodic inspections and maintenance be made. Inspection cycles differ by the kind of equipment, conditions of use, importance, frequency of trouble, dirt quantity, temperature, and quality of work.

(1) Check Lists

During maintenance, it is necessary to prepare check lists introducing inspection items, contents of inspections and inspection marks for each installation and piece of equipment from management standards. Maintenance check list is shown in the **Table 3-1**.

(2) Records

During maintenance, prepare inspection record tables before hand, and fill in measured dimensions of each component and others for use of future maintenance.

(3) Inspection Cycles

The concept of daily, monthly and annual inspections is described below.

1) Daily Inspections

Daily inspection check for any disorder before the operator operates any equipment and check equipment function by actual operation. If any disorder is found during these inspections, appropriate measures such as immediate repair should be taken for minor problems and entry made in record books.

2) Monthly Inspections

Monthly inspection and checking for problems should be done atleast once a month. This is performed by an operator on each piece of equipment. If any minor disorder is found in this check, appropriate measures such as immediate repair should be taken and entry made in record books. For a problem which is considered to have a major effect on the function or life of the equipment, appropriate measures must be taken in the form of a precise inspection by an expert.

3) Annual Inspections

Annual inspections check the total function of each piece of equipment. This is performed annually by operator and should be completed before an operation period. If possible, total trial operation should be accomplished during this inspection.

(4) Periodic Maintenance

Periodic maintenance is desirable to be executed once in 5 to 8 years, though it differs by the use of structures and repair of damage, wear and other abnormal component; and parts replacement is carried out on mechanic’s diagnosis. Before periodic maintenance of work based on pre-determined plan, tool preparation, necessary replacement items, packing, lubricating oil, etc. is necessary.

(5) Temporary Maintenance

Temporary maintenance is performed to prevent trouble and accidents before hand in event discrepancies are found during daily and periodic inspections other than periodic maintenance.

3.4 Canals

(1) Main and Secondary Canals

Stream water usually contains certain amount of suspended particulars, causing sedimentation in the canal. Eroded soil loss from field also gets into canal, resulting in the sedimentation in the canal. Maintenance work for canal should be done at least once before the irrigation season starts. Maintenance works required for the canal are; cleaning, weeding, de-silting, re-shaping, and also minor repairs as described below;

1) Earth canal

- Bushes and trees on the canal embankments should be removed. They may obstruct the water flow and their roots open the banks and develop leakages.
- Grasses, sediments and debris in the canal should be removed. While cleaning the canal, care must be so taken that the original shape of the cross-sections is kept. For this, a wooden frame with exact dimensions of the designed cross-section can be of great help.
- Crossing sections by people and animals (livestock) along the canal should be strengthened by hard compaction or lined with stones, bricks or masonry.
- Holes/cracks in the canal should be filled with sticky clay soil, and eroded sections should be rebuilt to the original shape.

2) Brick lined canal

- Grasses, sediments and debris in the canal should be removed.
- Cracks and water leaking point should be repaired with mortar.

(2) Division Box, Discharge Box and Turnout

Division box, discharge box and turnout are made of brick masonry and the same maintenance work as brick masonry canal is required. In addition, maintenance on stop-log grooves is required. Damaged stop-log grooves should be repaired and reshaped with mortar to meet to stop-log. In case the connection part to earth canal is scoured, the part should be reinforced with gravel laying. Maintenance check list is shown in the **Table 3-1.**

3.5 Maintenance Cost

Maintenance cost for each item is roughly estimated as shown in **Table 3-2**.

Table 3-1 Maintenance Check Lists

Maintenance Check List for River Diversion Weir

Item	Frequency	Point to be checked	Findings
1. River conditions	Daily	Water level	Enough or not.
	Daily	Water flow conditions	Stable or not. Flood, rich or drought.
	Daily	Sediment	If it is a lot to affect intake, it shall be removed.
		Others	Water quality, flotage etc.
2. Weir	Annually	Crack or damage of stone masonry	Small scale or large scale. Need repair or not
	At after	Erosion at abutment	Need repair or protection or not
	Annually	Water leakage	Small scale or large scale. Need repair or not
	Annually	Riverbed scouring at downstream	Need protection or not
	Daily	Sediment	If it is a lot to affect intake, it shall be removed.
	Annually	Damage of gabion	Small scale or large scale. Need repair or not
	Annually	Subsidence and deformation of gabion	Stable or not. Need repair or not.
		Others	
3. Intake	Annually	Crack or damage of stone masonry	Small scale or large scale. Need repair or not
	Daily	Sediment	If it is a lot to affect intake pipes, it shall be removed.
	Daily	Trash	If it is a lot to block intake pipes, it shall be removed
	Daily	Water level	Enough or not
	Monthly	Damage of pipes	Need repair or not.
	Daily	Function	Functioning or not.
		Others	
4. Others	Monthly	Conditions of stop log	Need repair or not.
	Monthly	Conditions of gate	Need painting, reapir or not.
		Protection bund	Collapse or erosion. Need repair or not.

Maintenance Check List for Water Impounding Dam

Item	Frequency	Point to be checked	Findings
1. Reservoir	Daily	Water level	Elevation
	Annually	Sediment	Depth
		Others	
2. Spillway	Annually	Crack or damage of stone masonry	Small scale or large scale. Need repair or not
	At after every flood	Erosion at abutment	Need repair or protection or not
	At after every flood	Erosion at downstream	Need repair or protection or not
	At flood time	Flow capacity	Enough or not (at flood time)
	At flood time	Flow condition at flood	Stable or not
	Annually	Conditions of channel	Damage, weeds etc.
		Others	
3. Dam embankment	Monthly	Crack at embankment	If there is, consult with irrigation engineer.
	Monthly	Erosion of embankment	Small scale or large scale. need repair immediately or not.
	Monthly	Collapse of embankment	Small scale or large scale. need repair immediately or not.
	Monthly	Water leakage at down stream	Small scale or large scale. expanding or not. Need repair immediately or not.
		Others	
4. Intake and outlet	Annually	Sediment	If it is a lot to affect intake pipe, it shall be removed.
	Daily	Trash	If it is a lot to affect intake pipe, it shall be removed.
	Daily	Function	Functioning or not.
		Others	
5. Others	Daily	Water quality	Affect to crops or not.

Maintenance Check List for Pump and Engine

Item	Frequency	Point to be checked	Findings
1. Diesel	Daily	Appearance	Need re-painting or not, Neede repair or not
Engine	Daily	Engine oil	Enough or not
	Daily	Fuel tank	Enough fuel or not
	Daily	Noise	Abnormal noise or not
	Daily	Vibration	Abnormal vibration or not
	Daily	Oil and fuel leakage	Any leakage
	Monthly	Various bolts for loosening	Tighten all bolts and nuts
	Monthly	Vent hole in the fuel tank cap	Cleaning
	Monthly	Battery	Water level
	Monthly	Fuel tank	Cleaning
	Monthly	Fuel filter	Cleaning
	Monthly	Engine oil filter element	Need replacement or not
	Monthly	Fuel filter element	Need replacement or not
	Monthly	Engine oil	Replacement at every 500hrs (10HP) or every 200hrs (41HP)
	Monthly	Paint condition	Need re-painting or not
	Monthly	Air cleaner	Cleaning or replacement
	Monthly	Fan velt	Adjust tension worn out or not
		Cylinder head portion(nozzle, valves	Adjustment, cleaning
		Shaft portion	Adjustment
		Main engine portion (piston, crank, etc)	Adjustment, cleaning
		Fuel injection system	Adjustment, cleaning
		Gasket	Need replacement or not
2. Pump	Daily	Vibration	Abnormal vibration or not
Equipment	Daily	Noise	Abnormal noise or not
	Daily	Water leakage	Small scale or large scale. Need repair or not.
	Monthly	Appearance	Need re-painting or not, Need repair or not
	Monthly	Loose bolts	Tighten all bolts and nuts
	Monthly	Coupling rubber wear	Need replacement or not
	Annually	Gland packing wear condition	Need replacement or not
	Annually	Grease	Greasing
	Annually	Shaft center misalignment	Adjustment
	Annually	Paint condition	Need re-painting or not
3.Others	Daily	Conditions of strainer.	Clogged or not. Cleaning
	Daily	Conditions of suction pipe	Damaged or not. (water leakage)

Maintenance Check List for Canal System

Item	Frequency	Point to be checked	Findings
1. Brick or	Daily	Water flow conditions	Smooth or not
concrete	Monthly	Crack or damage	Small scale or large scale. Need repair or not
lined canal	Annually	Conditions of drain ditch (along the main canal)	Functioning or not. Need excavation or not.
	Monthly	Sediment	Small scale or large scale. Need removal or not
	Monthly	Weeds	A lot or a few. Need clearing or not.
		Others	
2. Earth canal	Daily	Water flow condition	Smooth or not
	Monthly	Cross section area	Enough cross section or not
	Monthly	Erosion	Need repair or not
	Monthly	Weeds	Need clearing or not
		Others	
3. Road	Daily	Water flow conditions	Smooth or not
crossing and	Monthly	Sediment	Small scale or large scale. Need removal or not
gully crossing	Monthly	Crack or damage	Small scale or large scale. Need repair or not
	Daily	Trash	If it is a lot to block pipe, it shall be removed
		Others	
4. Structures	Daily	Water flow conditions	Smooth or not
(division box,	Monthly	Sediment	Small scale or large scale. Need removal or not
drop box	Monthly	Crack or damage	Small scale or large scale. Need repair or not
turnout)	Monthly	Conditions of stop log	Need repair or not
		Others	
5. Others			

Maintenance Check List for Pipeline System

Item	Frequency	Point to be checked	Findings
1. River	Daily	Water flow conditions	Stable or not, flood, rich or drought
conditions	Daily	Water level	Elevation
	Daily	Conditions of intake point	Enough depth or not, Any obstruction.
		Others	
2. Pipes	Monthly	Crack or damage	Small scale or large scale. Need repair or replacement.
	Monthly	Water leakage	Small scale or large scale. Need repair or replacement.
		Others	
3.. Discharge	Daily	Water flow conditions	Smooth or not
box	Monthly	Sediment	Small scale or large scale. Need removal or not
	Monthly	Crack or damage	Small scale or large scale. Need repair or not
	Monthly	Conditions of stop log and groove	Need repair or not
		Others	
4. Others			

Table 3-2 Maintenance Cost for Each System

No.	Item	Specification/Quality	Quantity	Unit	Unit Price MK	Price MK	Remarks
1	**River Diversion Weir**						
1-1	Annual maintenance						
(1)	Removal of sediment	unskilled labor	10.0	man	0.0	0.0	2man x 5 days
	Total		10.0	man		0.0	
1-2	Every 5 years						
(1)	Reapir of stone masonry	weir, intake	0.50	m^3			
	rubble stone		0.27	m^3	0.0	0.0	
	sand		0.20	m^3	0.0	0.0	
	cement	ordinary portland	2.25	bags	2,500.0	5,625.0	
	Fuel		10.00	lit	240.0	2,400.0	transportation
	material total					8,025.0	
	mortar mixing	unskilled labor	6.0	man	0.0	0.0	1day
	stone masonry	foreman	1.0	man	0.0	0.0	1day
		skilled labor	1.0	man	300.0	300.0	1day
		unskilled labor	5.0	man	0.0	0.0	1day
	labor total					300.0	
(2)	Repair of gabion						
	rubble stone		0.0	m^3	0.0	0.0	
	steel wire		1.0	kg	150.0	150.0	
	material total					150.0	
	gabion work	skilled labor	1.0	man	300.0	300.0	1day
	gabion work	unskilled labor	2.0	man	0.0	0.0	1day
	labor total					300.0	
	Every 5 years Total	material				8,175.0	
		labor				600.0	
2	**Water Impounding Dam**						
2-1	Annual maintenance						
(1)	De-silting of the reservoir		200.0	m^3			
	Excavation	unskilled labor	156.0	man	0.0	0.0	
	Hauling excavated material	unskilled labor	88.0	man	0.0	0.0	100m
	labor total					0.0	
2-2	Every 5 years						
(1)	Repair of Embankment		10.0	m^3			
	Embankment	unskilled labor	7.6	man	0.0	0.0	
	Hauling material	unskilled labor	4.4	man	0.0	0.0	100m
	Finsing slope	unskilled labor	1.2	man	0.0	0.0	10m^2
	labor total					0.0	
(2)	Repair of stone masonry		0.5	m^3			spillway
	rubble stone		0.27	m^3	10.0	2.7	
	sand		0.20	m^3	10.0	2.0	
	cement	ordinary portland	2.25	bags	2,500.0	5,625.0	
	Fuel		10.00	lit	240.0	2,400.0	transportation
	material total					8,029.7	
	mortar mixing	unskilled labor	6.0	man	0.0	0.0	1day
	stone masonry	foreman	1.0	man	0.0	0.0	1day
		skilled labor	1.0	man	300.0	300.0	1day
		unskilled labor	5.0	man	0.0	0.0	1day
	labor total					300.0	
	Every 5 years Total	material				8,029.7	
		labor				300.0	
2-3	Every 20 years						
(1)	Replacement of intake gate		1.0	set	150,000.0	150,000.0	
(2)	Replacement of outlet valve		1.0	set	150,000.0	150,000.0	
	Evry 20 years total					300,000.0	

3	Open Canal System						
3-1	Annual maintenance						
(1)	Cleaning canal	300m					
	unskilled labor		20.0	man	0.0	0.0	
(2)	Repair of earth canal						
	Re-shaping	unskilled labor			0.0	0.0	each plot owner
3-2	Every 3 years						
(1)	Repair of brick lining						
	equvalent to 10m construction		10.0	m			
	bricks		608.5	pcs	1.5	912.8	730.2x10/12
	sand		0.2	m^3	0.0	0.0	0.34x10/12x0.5
	cement	ordinary portland	2.6	bag	2,500.0	6,375.0	0.34x10/12x9
	material total					7,287.8	
	mortar mixing	unskilled labor	4.0	man	0.0	0.0	
	brick laying	skilled labor	1.0	man	300.0	300.0	
		unskilled labor	7.5	man	0.0	0.0	9*300/12
	labor total					300.0	
(2)	Repair of structures						
	equivalent to 1 box construction		1.0	box			
	bricks		223.0	pcs	1.5	334.5	223.0x1
	sand		0.1	m^3	0.0	0.0	0.15x0.8x1
	cement		1.4	bag	2,500.0	3,375.0	0.15x1x9
	material total					3,709.5	
	mortar mixing	unskilled labor	4.0	man	0.0	0.0	
	brick laying	foreman	0.3	man	0.0	0.0	0.33x1
		skilled labor	0.3	man	300.0	99.0	0.33x1
		unskilled labor	0.7	man	0.0	0.0	0.67x1
	labor total					99.0	
	Every 3 years Total	material				10,997.3	
		labor				399.0	
4	Motorized Pump System						
4-1	Annual maintenance						
(1)	Maintenance of Engine						
	Engine Oil		10.0	lit	740.0	7,400.0	
	Oil filter element		1.0	pc	700.0	700.0	
	Fuel filter element		1.0	pc	700.0	700.0	
	Air cleaner element		1.0	pc	2,000.0	2,000.0	
(2)	Maintenance of Pump						
	Grease		0.5	kg	720.0	360.0	
	Annual total					11,160.0	
4-2	Every 5 years						
(1)	Maintenance of Engine						
	Bearing		1.0	pc	1,200.0	1,200.0	
	Painting		1.0	set	1,600.0	1,600.0	
	Gasket		1.0	pc	1,200.0	1,200.0	
(2)	Maintenance of Pump						
	Gasket		1.0	set	1,300.0	1,300.0	
	Gasket maker		1.0	pc	650.0	650.0	
	Painting		1.0	set	1,600.0	1,600.0	
(3)	Pipeline						
	Replacement of pipes		2.0	pc	4,220.0	8,440.0	
	Every 5 years total					15,990.0	
	* Prices of spare parts varies according to the type of engine and pump.						
	* Prices are rough standard at the time of 2008.						

CHAPTER 4. Water Management of Irrigation Systems

4.1 Introduction

Eight verification sites were selected in the study to verify the proposed plans and procedures mentioned in the "Action Plan (A/P)". **Table 4-1** shows the summary indicating outline of the selected irrigation schemes for verification sites and needs of rehabilitation for irrigation facilities. Based on this summary table, current prevailing problems in the fields of irrigation water management of the Medium-Scale Irrigation Scheme were identified, and then rehabilitation and improvement subjects were listed up as the issues of the "Technical Guideline", as shown below:

- Uncertain hectarage in size for irrigation area
- No observation and identification of available water sources for irrigation
- No considerations of the required irrigation water requirement for planning and designing irrigation facilities
- Low awareness of water saving technology for irrigation by farmers/EPA
- No countermeasures for effective dam operation in case of drought year
- No record keepings on water management activities
- Areas facing poor drainage such as water loggings at farm level in wet season

⇩ Rehabilitation / Improvement

- Topographic survey to demarcate irrigation area
- Discharge measurements at rivers/creaks and irrigation canals
- Installation of staff gauges and observation of canal discharges by water level
- Estimation of irrigation water requirements
- Determination of water supply and distribution methods
- Formulation of reservoir operation rule
- Record keepings for water management
- Improvement of drainage conditions to alleviate water loggings at farm level

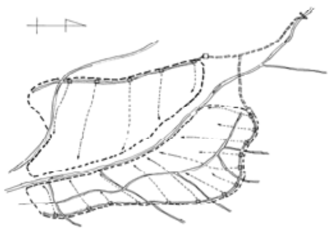
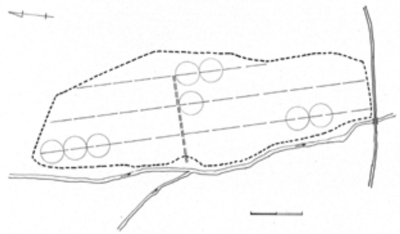
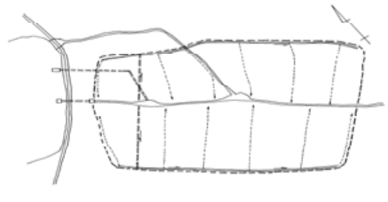
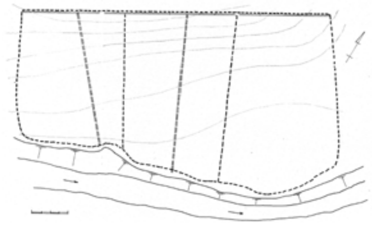
Subsequent deals with the discussions on these issues in terms of the "Technical Guideline" of the "Package Plan" in the field of irrigation water management.

4.2 Topographic Survey to demarcate Irrigation Area

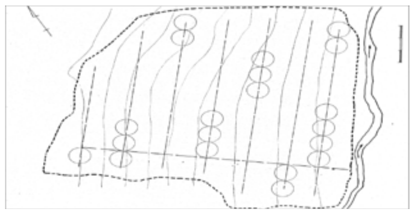
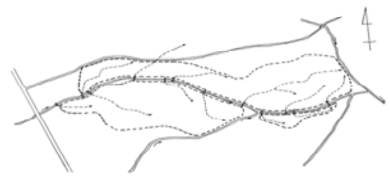
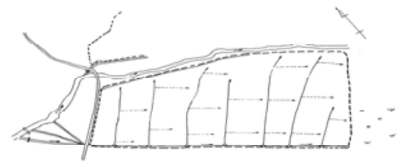
Topographic map for the scheme should be prepared to delineate the exact boundaries of the beneficial areas and also to estimate their irrigation areas. The preparation of topographic map would be done by the Irrigation Officers in District Agricultural Office (DAO) in the manner of simplified survey methods applicable for development of medium-scale irrigation schemes. The survey methods and procedures of them are specified as follows (refer to **Figure 4-1**) [1].

[1] In addition to the above two methods of topographic survey, the Study Team tried to introduce "the Plain Survey methods being popularly applied in Japan for preparation of topographic survey. However, related field level government officer in the Malawi did not agree willingly, which is thought to be no familiar with them.

Table 4-1 Outline of Selected Irrigation Schemes for Verification Sites and Needs of Rehabilitation for Irrigation Facilities (1/2)

Items	Selected Irrigation schemes for Verification Sites			
	Bethani Irrigation Scheme (Mz-11)	Mantha Irrigation Scheme (Mz-4)	Chiwoza Dam Irrigation Scheme (Kas-46)	Kachere Irrigation Scheme (Kas-40)
1. Location	ADD : Mzuzu District : Rumphi EPA : Mhuju Latitude : 10° 56′ 04″ S Longitude: 33° 55′ 10″ E Elevation : 1,063 m	ADD : Mzuzu District : Mzimba EPA : Luwelezi Latitude : 12° 29′ 42″ S Longitude: 33° 37′ 69″ E Elevation : 1,216 m	ADD : Kasungu District : Kasungu EPA : Chulu Latitude : 12° 52′ 72″ S Longitude: 33° 19′ 32″ E Elevation : 1,004 m	ADD : Kasungu District : Kasungu EPA : Kuchipala Latitude : 13° 12’ 44″ S Longitude: 33° 39′ 62″ E Elevation : 1,043 m
2. Type of Technology and Schematic Diagram of Scheme	Technology : River diversion type 	Technology : Motorized pump type 	Technology : Water impounding type and motorized pump type 	Technology : Motorized pump type 
3. Outline of the Scheme	- Scheme was constructed by the Government of Malawi (GoM) in 2003-2004 under the Rural Income Enhancement Project (RIEP) funded through ADB loan. The project was mainly implemented through a process of participatory approaches. - Scheme is divided into two systems; Bethani-A (area: 8 ha) and Bethani-B (area: 14 ha) located on the both banks of the Luviri River. Both sites are tapping irrigation water from same site of diversion weir in the Luviri River.	- Scheme was initiated by agricultural staff (AEDO) in 2000, and pump was provided by NGO of Telefood. - The pump was operated for only one year for the dry (winter) season crops in 2002. However, pump operation was stopped in 2002, due to lack of money to purchase fuels, inadequate maintenance works of pump facilities, and also following reasons; ・ No mechanical maintenance service by government and NGO after 250 hours operations of pump ・ No training on pump operation and maintenance by government and NGO (no operation manual) - Irrigated area was 18 ha for wet season and 22 ha for dry season.	- Chiwoza dam was constructed by British Government in 1962 for the purposes of dipping of livestock, and it was broken down in 1985 due to flood. Dam was followed up by the District Commissioner’s (DCS) Office, so that the dam maintained. However, it did not work effectively. - In the year of 2000, Chiwoza Dam Irrigation Scheme was started, but the scheme faced with a lot of problems, so rehabilitation works of the dam were implemented under the program of MASAF funded by WB in 2003. - In the year of 2004, MALEZA (NGO in Kasungu base) constructed 71 m of lined main canal at the right bank, and also repaired again embankment portions of the dam. Pump and engine (diesel) with 10 Hp were procured by GoM through the “Bua-Dwangwa Mitigation Project”during the period from July 2006 to June 2007.	- Scheme was established in 2006 under the assistance by MASAF of WB funds, and two units of pumps and 600,000 MK to procure fuel and input materials, including maize and vegetable seeds was grant to the group, because of hunger sue to heavy dry spell in 2006. - Present irrigation areas covering 13 villages are 6.4 ha. Beneficial members in 2006 were 72 households, but these figures were increased in 87 households in 2007.
4. Water Management Conditions	- Irrigation water supply during wet season is not basically needed, but exceptionally supplemental water supply was made in the periods of dry spells in 2004 and 2005. - Water distributions in Bethani-A and Bethani-B are made with 5-day rotation (Monday to Friday) in the main canal systems, and each block can get water for two days continuously. - Water supply from the main canal to the field is made through feeder canals, but these feeder canals are provided on the relative steep slope in the direction of perpendicular to contour line, resulting in soil erosion around feeder canals.	- Irrigation water supply by means of sprinkler was made at a frequency of 3 times a week, and its pump operation hours were four to five hours a day. - No water distribution rules such as rotational water supply were established, and irrigation water was distributed depending upon farmers request on the basis of soil moisture at field. - Water loggings at farm leve bserved during the wet season at the lower areas along the Ruwelezi River, due to poor drainage systems and relative flat topographic conditions.	- Irrigation water sources are reservoir, of which catchment area is 2.4 sq.km, and is presently diverted by opening outlet valve provided at outlet structure of the reservoir. The diverted water is released to the existing Chisuwe River. The released water is lifted by motorized pump to main irrigation canals provided at the both banks of area. - Reservoir is presently silted by the sediment materials, because of no periodical dredging works since construction, except for following one dredging works during the September – October in 2001. - Present average water depth is about two meters	- Irrigation for dry season is the main activity, while that in wet season is supplemental irrigation. Pumps are placed along the Bua River to irrigate areas, which are divided into 3 zones of A, B and C, and are shifted in accordance with needs for irrigation to the areas. - Water delivery point is a little bit elevated point (pipe length is about 200m), then lifted water is flow down by gravity through secondary canal. Irrigation period for each zone is 2 day with water supply of 10 hr from 6:00 am to 16:00 pm. Irrigation method is basin (5.0 m x 1.0m on average), which are instructed by EPA extension officers.

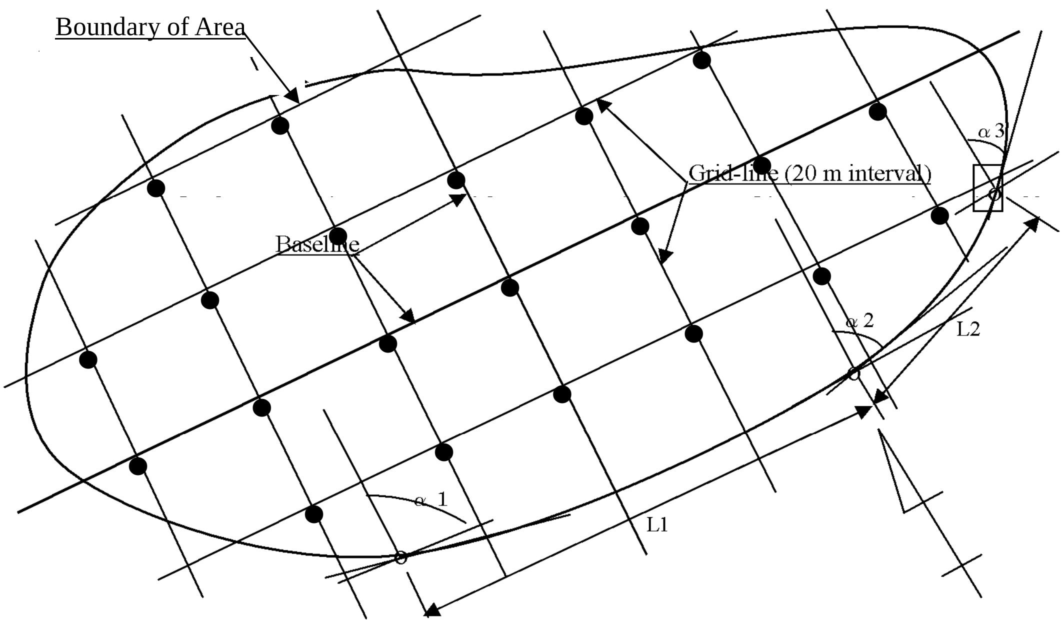
Items	Selected Irrigation schemes for Verification Sites			
	Bethani Irrigation Scheme (Mz-11)	**Mantha Irrigation Scheme （Mz-4）**	**Chiwoza Dam Irrigation Scheme (Kas-46)**	**Kachere Irrigation Scheme (Kas-40)**
	- An effective control of water at each division box is not done due to unsuitable devices (wooden Plate) for discharge control. - Excess water is supplied to the field due to no effective timber plate operation at division boxes, these conditions causes the irrigation water shortage at downstream area in Bethani-B, especially at the extension areas located the most downstream of the Bethani-B system.		(max. depth is 2.5 m), and storage volume could approximately be estimated at 65,000 m3 at full water level, according to the results of reservoir area survey. - Lower areas along the Chisuwe River are presently irrigated by gravity flow through outlet valve depending on an effective water heads between reservoir water level and outlet elevation (3.4 m to 4.4 m). - The outlet valve is operated by Committee Member with an interval of once a week for right and left bank areas individually. Irrigation water supply continues for 2-day for daytime only from 6:00 am to 4:00 pm.	- Water loggings are observed during the wet season at the lower areas along the Bua River, due to poor drainage systems and relative flat topographic conditions.
5. Major Irrigation Facilities	- River diversion weir and intake structure : Stone masonry - Pipline : 2 lines x 350 m, PVC 140 mm, galvanizing pipe 140 mm - Division box : 5 boxes (Bethani-A) and 13 boxes (Bethani-B) - Sediment flash structure with gate value (2 places) (2 times of operation a month) - Main irrigation canals: 700 m (Bethani-A) and 1,500 m (Bethani-B) - Main irrigation canals for extension areas : 1.0 km (Bethani-A) and 0.4 km (Bethani-B) - Feeder canals (earth h canal) with an interval about 100m on average.	- 1 unit of pumps (diesel engine of Greaves Ltd in India, 41 Hp, 1,800 rpm) - Pipe line (dia = 140 mm 30 pipes, 100 mm x 25 pipes, 70 mm x 40 pipes) and sprinkler equipment	- Reservoir (embankment, intake structure, mechanical spillway, emergency spillway and canals) and outlet valve - Pumps and engine (VALIANT diesel engine, 10 Hp, 1,500 rpm, SATE-30, Indian made) - Irrigation canals Right main canal : L = 250 m (71m lined canal by brick), Area = 6 ha with 33 farmers) Left main canal : L = 250 m (earth canal), Area = 4 ha with 30 farmers - PVC pipe (dia = 110 – 90 mm x 6 m, 14 pipes)	- Pump facilities (2 units of centrifugal diesel engine of 10 Hp, VALIANT India made). One pump is presently breakdown. - 180 m of PVC Pipe (dia = 90 mm, 30 pipes x 6 m). This pipes are used for both pumps - Main and lateral canals, which are small-size of earth canal, are provided.
6. Needs of Rehabilitation of Facilities and Training	- Rehabilitation of diversion weir (de-silting of deposited materials) and intake structure - Rehabilitation of canal with canal lining - Newly provision of distribution boxes, drop structures and pipe crossings	- Change of water supply methods from sprinkler systems to open (surface) canal systems, - Repairing and checking of pump and engine - Construction of canal systems with brick lining canal systems - Training on water distribution management to achieve a skill on the new irrigation technology of open (surface) canal systems, because farmers group has no experiences for distribution arrangement on new systems.	- Repair and extension of main canals (right and left main canals of 650 m each) - De-silting of reservoir - Repair of spillway - PVC pipe (dia = 75 mm) - Pump discharge pipe, flat vinyl pipe (L=60 m) - Repair of outlet valve - Trainings on water distribution management to improve irrigation water supply conditions at each sub-irrigation system as well as field level.	- Minor rehabilitation for one unit of pumps - Construction of lined main canal (brick) and provision of PVC pipes (dia = 90 mm) to prevent from conveyance water losses under sandy loam of soil textures. - Trainings on water distribution management to improve irrigation water supply conditions at each sub-irrigation system as well as field level.

Items	Selected Irrigation schemes for Verification Sites			
	Titukulane Irrigation Scheme (Kas-47)	**Chaseta Irrigation Scheme (Li-2)**	**Bawi Irrigation Scheme (Li-21)**	**Chibwana Irrigation Scheme (Ma-1)**
1. Location	ADD : Kasungu District : Dowa EPA : Nachisaka Latitude : 13° 35′ 59″ S Longitude: 33° 58′ 08″ E Elevation : 1,187 m	ADD : Lilongwe District : Lilongwe EPA : Mlomba Latitude : 14° 20′ 05″ S Longitude: 33° 48′ 67″ E Elevation : 1,204 m	ADD : Lilongwe District : Ntcheu EPA : Manjawira Latitude : 14° 52′ 78″ S Longitude: 34° 49′ 32″ E Elevation : 817 m	ADD : Machinga District : Machinga EPA : Nsanama Latitude : 15° 04′ 81″ S Longitude: 35° 31′ 31″ E Elevation : 615 m
2. Type of Technology and Schematic Diagram of Scheme	Technology : River diversion type 	Technology : Motorized pump type 	Technology : River diversion type 	Technology : River diversion type 
3. Outline of the Scheme	- Scheme (irrigation area is 7 ha) was initiated in 2002 supported by GoM, and about 4.0 km of irrigation canal was excavated by farmers group for the period of 3 month. - In 2005, diversion weir made by masonry was constructed under the MASAF funds (WB), and this weir was only used for irrigation water supply for 2006 dry season cropping. But the flood occurred in March 2006 washed away the right bank protection of the weir. - Under the situations, no irrigation practices by means of Titukulane main irrigation system are carried out during the dry season in 2007. - To irrigate small areas in the scheme two small canals so called as small-scale irrigation scheme supplying irrigation water are observed to convey water. - In June 2007, Dowa District Office using the funds of Farm Income Diversification Programm (FIDP) gave 5-bags of cement to the farmers group to repair the damaged weir, and the group constructed temporary protection structure (masonry made) at the right bank.	- Scheme (irrigation area is 12 ha) was started in 1999 with a support of GoM. However, at present, no pump operation is made, due to damage of suction and delivery pipes by fire disaster in 2001. Pump had operated only in one cropping season of 2001. - Irrigation water supply at field was made by means of sprinkler method. - In 2003, Lutherne (local NGOs) provided gravity system of irrigation canal (L=200 m) with pump (capacity = 5 Hp) to supply water for 2 ha of land, and water supply was made for two years from 2003 to 2005. However this scheme was no sustained because of taking out of pump equipment in 2005 by the NGO. 20 farmers used this canal for areas of two hectares.	- Scheme was started in 1949 with several temporary brush dams constructed in the Bawi river by beneficiary farmer themselves, and managed individually. - Present irrigation systems comprises of 12 sub-irrigation systems, of which total irrigation areas are 14.7 ha with 12 weirs. - Out of these 12 sub-systems, weirs of No.5 (Mangulenje) and No.7 (Adam) were constructed by stone masonry structure, while other 10 weirs were made by the local materials using wood, brush and soils as a form of temporary weir. However, No.7 weir was washed away by flood occurred in 2005 wet season.	- Scheme was started in1979 with an assistance of GoM, and intake structure and irrigation canal were constructed. But due to inadequate location of the intake structure, the required amounts of water could not be diverted from the Sumulu river. - Therefore, farmers themselves excavated new intake and connection canal at a little upstream of the previous one in 1993. However, since this intake was constructed at the main stream of the river, the excessive amounts of water from the river were diverted in the wet season. These conditions caused the damages to irrigation canals and related structures. - Under the conditions, IFAD constructed another new intake together with gabion weir and provision of the lining of main canal (L =700 m) under the Smallholder Flood Plain Development Project (SFPDP) to meet requirement for the Sumulu Irrigation Scheme located in the downstream of the Chibwana scheme. At present 85 ha of areas are irrigated using these new intake and canal systems.
4. Water Management Conditions	- Rotational irrigation water supply was planned at a frequency of twice a week, but these water supply practices were not well managed by farmers group. - Irrigation water supply during the wet season is basically no necessary, because of enough rainfall. However, maize, cabbage, tomatoes, etc. need supplemental water supply, whenever consecutive no rainy days were happened, even though the wet season.	- Irrigation water sources of the Diamphwe river are big enough to irrigate the areas of 12 ha, and pump operation was made at the interval of one times a week during dry season of June to November (6 month). - Pump operation was made for two hours/day for 12 ha. Main crops during the dry season were green maize, cabbage, tomato, Chinese cabbage, Irish potato, etc. Fuel consumption was 50 lit./2 hr (total annual consumption : 50 lit x 4 times x 6 month x	- Irrigation water supplies at weir basis are scheduled in rotation in a week, that is, 3-day water supply for the right bank areas and latter 3-day water supply for the left bank areas. At the on-field level following irrigation water supply is presently practiced as a rule; Dry Season: "Basin Planting Irrigation Method" is commonly practiced considering effective utilization of	- Six division boxes made of brick structure are provided in main canal to divert irrigation water to secondary canal, but only two division boxes at the most upstream area are functional at present, and others are no functional because of being broken down. Under the situations, no operation rules to distribute irrigation water exist in the scheme, and frequent conflicts to get water to their fields are happening among farmers groups.

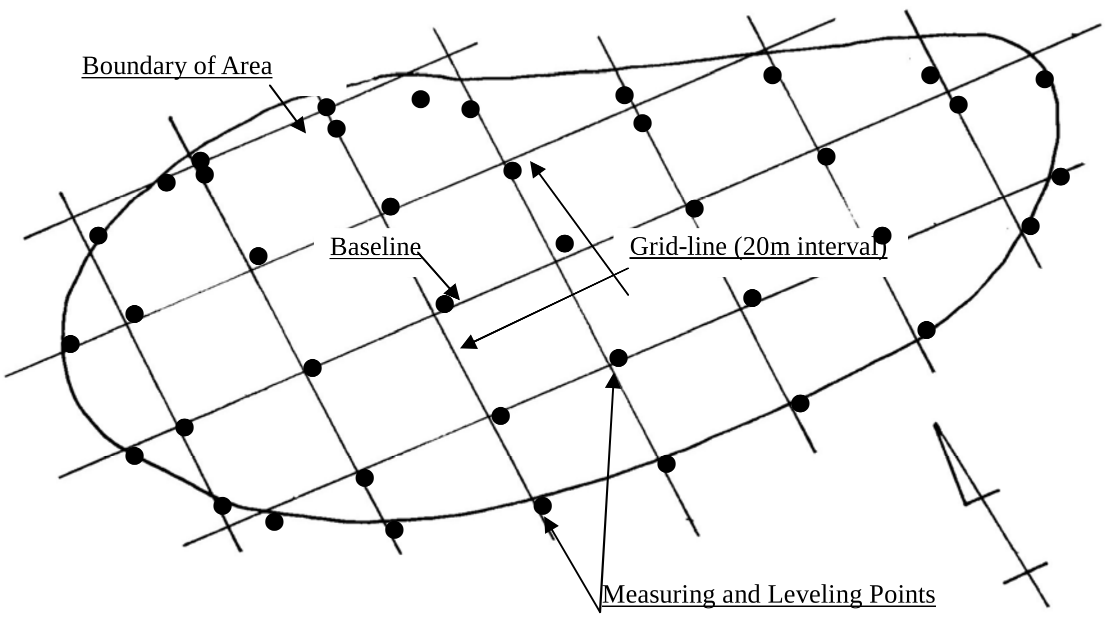
Items	Selected Irrigation schemes for Verification Sites			
	Titukulane Irrigation Scheme (Kas-47)	Chaseta Irrigation Scheme (Li-2)	Bawi Irrigation Scheme (Li-21)	Chibwana Irrigation Scheme (Ma-1)
		150 MK/lit = 189,000 MK), and average farmers payment for fuel was 200 MK/month/household. - Present irrigation practices are made by watering cane method using dug-well water and treadle pumps provided by EPA in 2004. - Water loggings at farm level are observed during the wet season at the lower areas along the Diamphwe River, due to poor drainage systems and relative flat topographic conditions.	scarce water resources, and irrigation water supply is normally scheduled once a week. Wet Season: Supplementary water supply is made under the "Ridge Planting Irrigation Method", because of heavy rainfall. - Irrigation canals are maintained by farmer group at a frequency of 3 to 4 times a month, and beneficiaries have to pay maintenance fees of 100 MK/season.	- At the initial stage of the scheme, main crops were rice in the wet season (85 ha), while maize (85 ha) in the dry season, but at present rice is planted in the wet season (85 ha) as same to the before, but in the dry season maize (15-20 ha) and rice (limited area only) are planted relying on the limited water resources of the Sumulu river. - Average yield of rice is 3.5 ton/ha, while 1.5 ton for local variety maize and 2.5 ton for hybrid variety maize. Rice is more profitable.
5. Major Irrigation Facilities	- Diversion weir (made by masonry, L= 10 m) - Irrigation canal (earth canal, L= 4.0 km)	- Pump (Model: Premier Irrigation Equipment T-5/19P, Suction Pipe = 136 mm, Revolution Speed = 1,800 rpm, Indian made) - Engine (Type : Air Cooled Diesel Engine, Model : Gresves Limited YWA MK5, Output : 41 Hp) - Delivery pipes (ϕ = 140 mm : 6 m x 25 pipes, ϕ = 100 mm : 6 m x 33 pipes, ϕ = 70 mm : 6 m x 16 pipes) - Raiser (stand pipe : 5 sets) - Gravity type irrigation canal with brick lining (L = 200 m)	- The stone masonry weirs of No.5 and No.7 were built under the "Public Work Program" supported by EU in 2003 under the following situations; ・ A lot of works and embankment materials as brush and soils were needed at the beginning of the dry season every year to re-built the temporary diversion weirs. ・ Temporary diversion weirs were not able to supply stable water to fish pond, especially wet season due to no provision of weirs. ・ Temporary weirs were easily broken down by other sub-system members because of conflict for getting water to their own land. - Main canals made of earth material for No.5 and No.7 have the length of 1.5 km and 1.8 km covering the areas of 3.5 ha and 2.8 ha, respectively.	- Diversion weir made by gabion was constructed by IFAD in 2004 (L = 15 m, h = 1.0 m) - Intake structure with sluice gate was constructed by IFAD in 2004 (concrete structure) - Main irrigation canal, which is lined by concrete was constructed by IFAD in 2005
6. Needs of Rehabilitation of Facilities and Training	- Rehabilitation of diversion weir, especially right bank protection works - Provision of intake structure of main canal - Newly provision of river crossing structure (brush dam or pipe crossing)	- The original irrigation system was of sprinkler water supply method under the category of motorized pump type. However, in the courses of workshop meeting held on site, farmers group stated the change of water supply methods from sprinkler systems to open (surface) canal systems. - Under the situations, farmers group emphasized the needs for trainings on water distribution management to achieve a skill on the new irrigation technology of open (surface) canal systems. - Repairing and checking of pump and engine, including suction pipe and battery - Construction of canal systems with brick lining (changes from sprinkler method to open (surface) canal systems)	- No.5 weir needs minor repair with masonry material with intake regulation structures - No7 weir needs to re-built with new permanent weir - Improvement of canal alignment and provision of canal lining - Provision of "division boxes" at diversion points in canal systems to divert water effectively. - Provision of flood protection bund - Trainings on water distribution management among 12 sub-irrigation schemes to improve irrigation water supply conditions at each sub-irrigation system as well as field level.	- Minor rehabilitation of gabion weir (raising crest elevation of about 50 cm) is needed to raise water level. - Rehabilitation and expansion of the main canal and also provision of secondary canals - Rehabilitation of division boxes to divert water from main canal to secondary canals. - Provision of polder dike to protect flood, which will occur periodically in January to February due to high water level of the Sumulu River. - Trainings on water distribution management to improve irrigation water supply conditions at each sub-irrigation system covered by seven division boxes

Figure 4-1 Illustration of Topographic Survey Methods

Topographic Survey Method (Type-1)



Topographic Survey Method (Type-2)



Survey Methods and Procedures (Type-1)

- i) Perimeter survey for the scheme (angle against magnetic north line (α) and length (L) using compass and measuring tape or chain) with driving in piles
- ii) Topographic and leveling survey using leveling equipment at intersection points with 20 m interval on the basis of baseline
- iii) Drawing of topographic map with an adequate scale
- iv) Production of contour lines

Survey Methods and Procedures (Type-2)

- i) Decision of scheme perimeter with driving in piles by means of reconnaissance survey
- ii) Provision of baseline at the center of the delineated area
- iii) Provision of 20 m interval lines intersected at right angle with the baseline
- iv) Topographic and leveling survey using leveling equipment at intersection points with 20 m interval
- v) Drawing of topographic map with an adequate scale
- vi) Production of contour lines applying topographic map preparation software of "Surfer 8", which is only available at ADD Level.

Drawings

Scale of Drawing is different depending on the size of survey areas as follows;

Area ≧ 10 ha --- 1 : 1,000
Area ＜ 10 ha --- 1 : 500

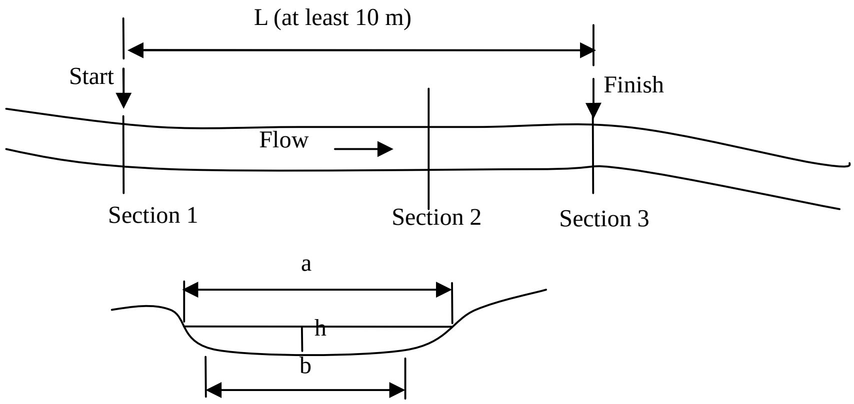
After delineation of the beneficial areas, irrigable areas covered by each lateral/feeder canal should be decided. These areas are the base for estimation of irrigation water requirements.

4.3 Discharge Measurements at Rivers / Creeks and Irrigation Canals

(1) Float Methods

River or creak discharges can be estimated when the stream is in a well-defined channel with a flow that would carry a small float such as a plastic water bottle or a wooden stick. By using a plastic water bottle or a stick, the discharges could be estimated by multiplying the flow velocity to be measured at which a float is carried along by the average cross-sectional area of the stream. This method can be described below.

Procedures for Estimating Discharge Flow



Procedure:

1. Select a straight section of the stream/creak at least 10 m long. The shape of the stream/creak along this section should be as uniform as possible.
2. Place a stake in the bank at the upstream end of the selected section (1) and measure 10 m downstream.
3. Place a stake at the downstream end of the selected section of the stream (3).
4. Place the floating object in the center of the stream at least five meter upstream of section

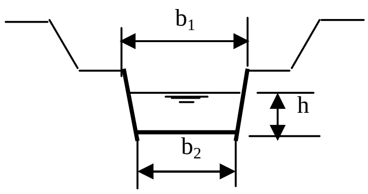
(1), and start timing when the object reaches section (1).

5. Stop timing when the floating object reaches section (3), and record the time in second.
6. Repeat steps 4 and 5 at least four times in order to determine the average time necessary for the stick to travel from section (1) to (3). The stick should not touch the stream bank during the trial. If it does, repeat the run and do not include the time for the bad trial when calculating the average time.
7. Measure the following in the selected stream section: the stream width (b), the surface water width (a), and the water depth (h). The cross section width in the selected portion of the stream will not be regular, and so (a), (b) and (h) need to be measured in several places to obtain an average value.
8. Calculate the average area of the stream cross-section (A), using the following equation:
   A =1/2 x (a +b) x h
9. Calculate the average flow velocity (V)
   V = 0.8 x L/t (m/sec)
   Where;
   t = Average travel time (sec)
   L = Distance between section (1) to (3) (m)
   0.8 = Reduction factor because not all the water flow as fast as that in the center
10. Calculate the flow discharge (Q) in the stream, using the following equation:
   Q = V x A (m^3/sec)

(2) Manning Methods

In order to estimate the canal discharges in case of uniform flow with trapezoidal or rectangular canal section, following "Manning Formula" developed hydraulically can be applied.

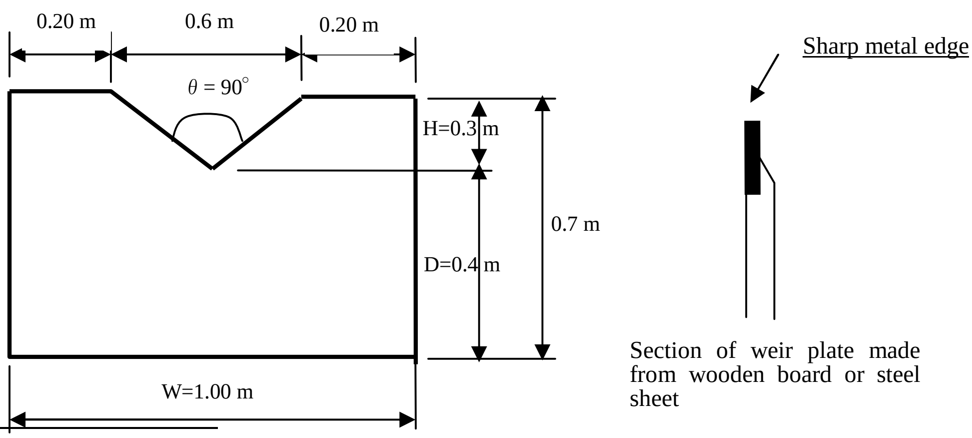
Q = A x V (m^3/sec)
Where ;
Q = Canal discharge (m^3/sec)
A = Canal cross section (m2) : 1/2 x (b_1 + b_2) x h
V = Flow velocity (m/sec) : 1/n x $R^{2/3}$ x $I^{1/2}$
h = Water depth (m)
n = Roughness coefficient: 0.016
I = Gradient of canal: 1/2,000



(3) V-Notch Methods[2]

For the small flows, a 90° V-notch weir can be used. Following figure shows a small and portable that can be easily made in a workshop at a low cost.

<u>90 Degree V-Notch Weir</u>



[2] Quoted from Field Guide on Irrigated Agriculture for Field Assistants, FAO, April 2001

The weir is set up across the stream so that all the water flow passes over the weir. It is normally necessary to seal around the base and sides of the weir plate with soil to ensure that water flows through the V-notch rather than under or around the sides of the plate. It is important that the top edge of the weir is horizontal.

The depth of water flowing over the notch is measured using a portable scale or ruler placed at least three meter upstream of the weir. The flow can then be found from following table, which shows the depth of water flowing over the weir to flow in liters per second. A V-notch weir can only be used where the water level on the downstream side does not interfere with the flow through the Vee.

Flow Rates measured with a 90° V-Notch Weir

Over Flow Depth on V-Notch (mm)	Discharge Q (lit/sec)	Over Flow Depth on V-Notch (mm)	Discharge Q (lit/sec)
40	0.45	170	16.60
50	0.78	180	19.15
60	1.23	190	21.92
70	1.81	200	24.92
80	2.52	210	28.15
90	3.38	220	31.62
100	4.41	230	35.34
110	5.59	240	39.31
120	6.95	250	43.53
130	8.49	260	48.02
140	10.21	270	52.76
150	12.14	280	57.79
160	14.26	290	63.09

Flow rates (Q) are expressed by the following equation;

$$Q = 8/15 \times C \times 2g^{1/2} \times H^{5/2}$$

Where;

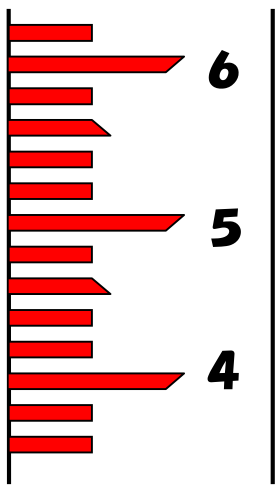
C : Flow coefficient 0.59

H : Overflow depth on V-notch (m)

g : Acceleration due to gravity, 9.8

When a V-notch weir is used to measure the flow rate, the following should be checked;

- Full stream flow passes over the weir (seal the edge of the weir plate to the banks and bed with clay from the stream bank)
- Weir plate is level (from side to side) and vertical (not learning forwards or backwards)
- Weir is in the center of the stream
- Measuring portion of the gauge should be at least three meter upstream of the weir



4.4 Installation of Staff Gauges and Observation of Canal Discharges by Water Level

In the "Manning Formula" methods mentioned in the above, the water depth (h) of canal can be measured by staff gauges to be installed.

(1) Fabrication and Installation of Staff Gauge

- Staff gauges made of iron plate can be procured, although painting of scale on the wooden timber would be possible at the major towns in each ADD.
- Staff gauges can be installed on the side-wall of the lined canal, at the river side and in the reservoir.

- It is ensured that the location of the staff gauges should not be affected by the turbulence of flow so that accurate gauge readings can be made.

(2) Development of Discharge Rating Curve ("Stage-Discharge Curve")

Discharge rating curve ("Stage-Discharge Curve") is useful to get corresponding discharges to be converted from the observed water depth. The Stage-Discharge Curve" can be shown by calculating discharges applying the above-mentioned "Manning Formula".

Figure 4-2 shows the "Stage-Discharge Curve" thus calculated, and their tabulation of the "Stage-Discharge Table" in case of the Chibwana Irrigation Scheme.

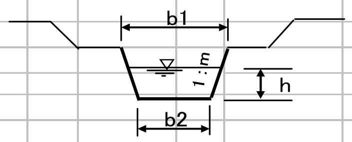
(3) Observation of Canal Discharge

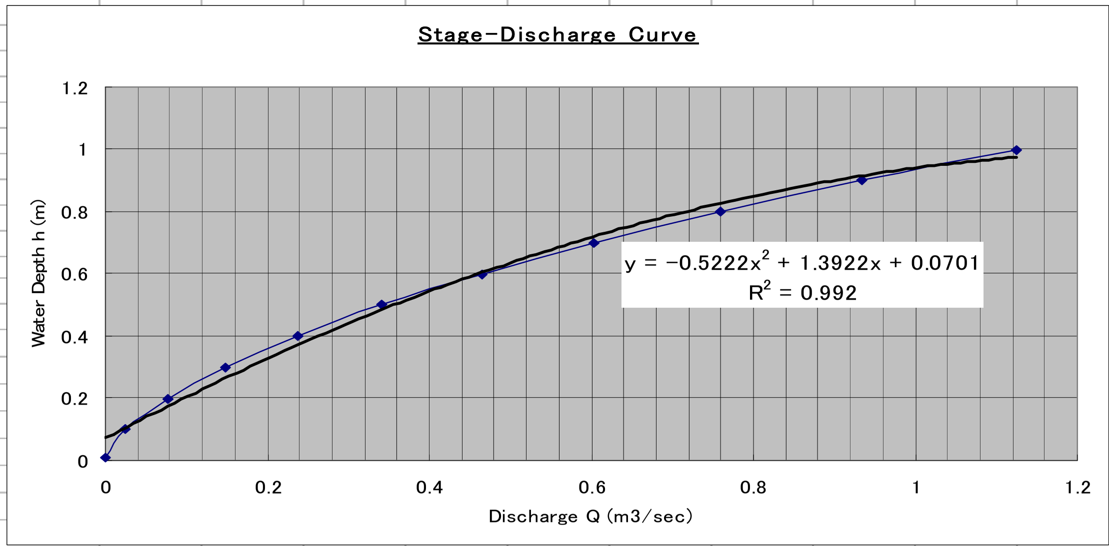
Canal water level at the main canal should periodically be observed by the members of "Water-Board Sub-Committee" at the fixed time every day. These water levels should be converted to the quantity of discharges using the above "Stage–Discharge Table", and recorded in the record book.

Figure 4-2 Stage-Discharge Curve showing Main Canal Capacity (in Case of Chibwana Irrigation Scheme)

Dimension of Canal

b1	1.9	m	
b2	0.9	m	
m	0.5		
I	0.0005		(1/2,000)
n	0.016		





Main Canal Discharges in Chibwana Irrigation Scheme

Water Depth	Canal Discharge Q (m^3/sec)									
H(m)	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	0.001	0.002	0.004	0.006	0.008	0.011	0.014	0.018	0.021
0.1	0.025	0.029	0.034	0.039	0.043	0.049	0.054	0.059	0.065	0.071
0.2	0.077	0.083	0.09	0.097	0.104	0.11	0.118	0.125	0.133	0.14
0.3	0.148	0.156	0.165	0.173	0.182	0.191	0.199	0.209	0.218	0.227
0.4	0.237	0.247	0.257	0.267	0.277	0.288	0.298	0.309	0.32	0.331
0.5	0.342	0.354	0.366	0.377	0.389	0.401	0.414	0.426	0.438	0.451
0.6	0.464	0.478	0.491	0.504	0.518	0.532	0.546	0.559	0.574	0.588
0.7	0.603	0.618	0.633	0.648	0.663	0.679	0.695	0.71	0.726	0.743
0.8	0.759	0.776	0.793	0.81	0.826	0.844	0.861	0.879	0.896	0.915
0.9	0.933	0.951	0.97	0.989	1.007	1.027	1.045	1.065	1.084	1.105

4.5 Estimation of Irrigation Water Requirements

(1) Climate and Meteorological Data

In the aspects of irrigation water management, estimation of irrigation water requirements is one of the essential elements to formulate the development plan for the irrigation schemes in each ADD. In the process for estimating the irrigation water requirements, the reference crop evapo- transpiration (ETo) for maize and upland crops could be estimated using the "CROPWAT 4 for Windows Computer Software" [3], being popular in the agricultural development plan in Malawi, which is based on the FAO Penman- Monteich Equation. On the other hand, the ETo for paddy rice could be estimated using the modified Penmam Methods. The Penman-Monteith equation is given by the following equation:

$$ETo = \frac{0.408\,\Delta(Rn - G) + \gamma \dfrac{900}{T + 273} U2(es - ea)}{\Delta + \gamma(1 + 0.34u2)}$$

Where;

ETo	=	Reference evapo-transpitation (mm/day)
Rn	=	Net radiation at the crop surface (MJ/m^{2}per day)
G	=	Soil heat flux density (MJ/m^{2}per day)
T	=	Mean daily air temperature at 2 m height (℃)
U2	=	Wind speed at 2 m height (m/sec)
Es	=	Saturation vapour pressure (kpa)
Ea	=	Actual vapour pressure (kpa)
Es – ea	=	Saturation vapour pressure deficit (pka)
△	＝	Slope of saturation vapor pressure curve at temperature T (kpa/℃)
γ	=	Psychometric constant (kpa/℃)

Crop water requirements (ETc/CWR) were estimated by multiplying ETo mentioned in the above by a crop coefficient (Kc), that is:

ETc = ETo x Kc

Where;

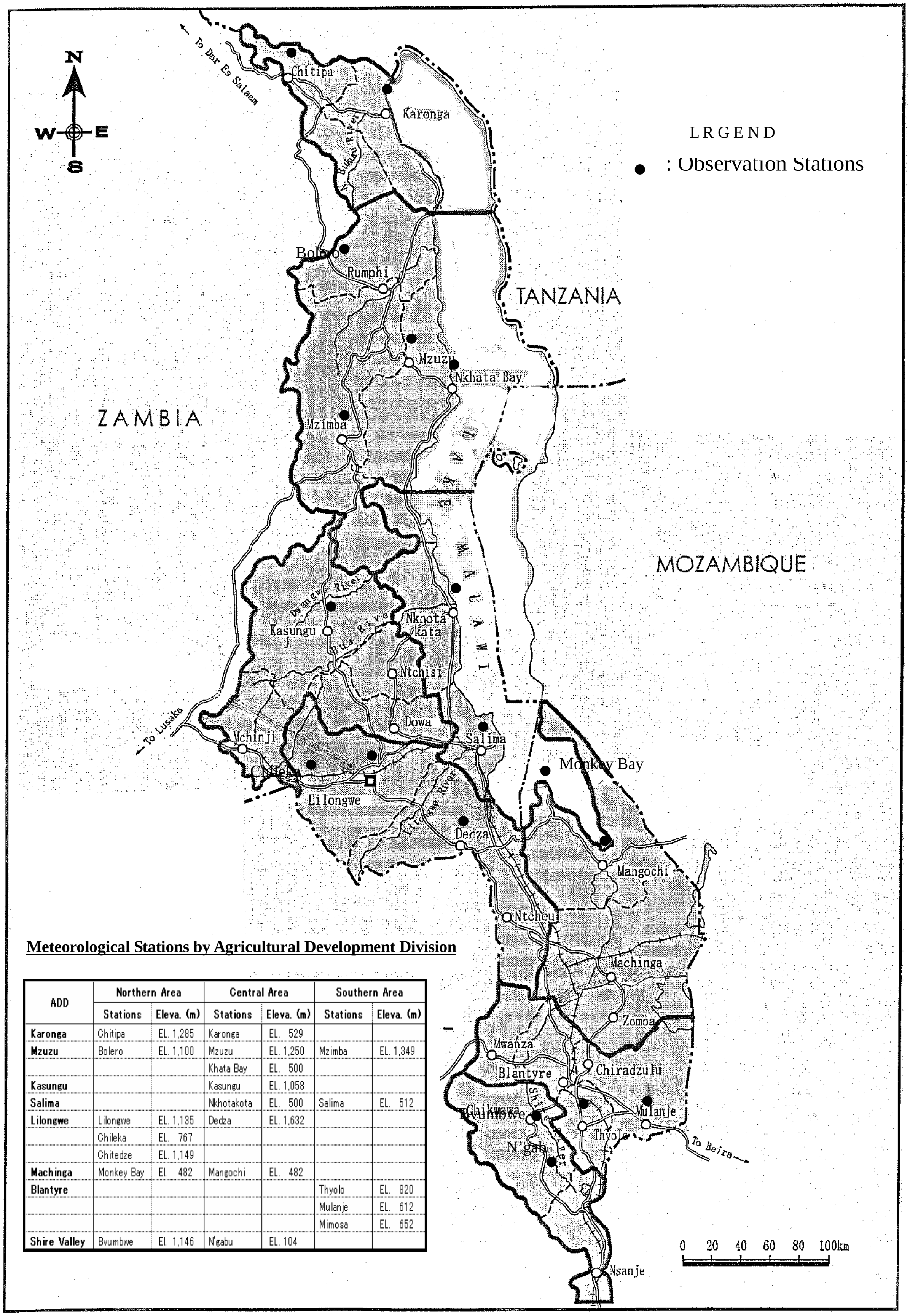
ETc/CWR	=	Crop water requirements (mm/day)
ETo	=	Reference crop evapo-transpiration (mm/day)
Kc	=	Crop coefficient

The above mentioned climatic and meteorological data presenting representative stations in each ADD were collected from the Meteorological Department, Ministry of Transport and Communication in Blantyre.

Figure 4-3 shows the location map of climatic and meteorological observation stations in eight ADD, and also **Table A.2-1** in the Attached Data shows tabulated climate and meteorological data observed at each station.

[3] Detailed procedures for the "CROPWAT 4 for Windows Computer Software" are referred to "attached Data-1: Manual for CROPWAT 4 Windows Computer Software".

Figure 4-3 Location Map of Meteorological Observation Stations in Eight ADD



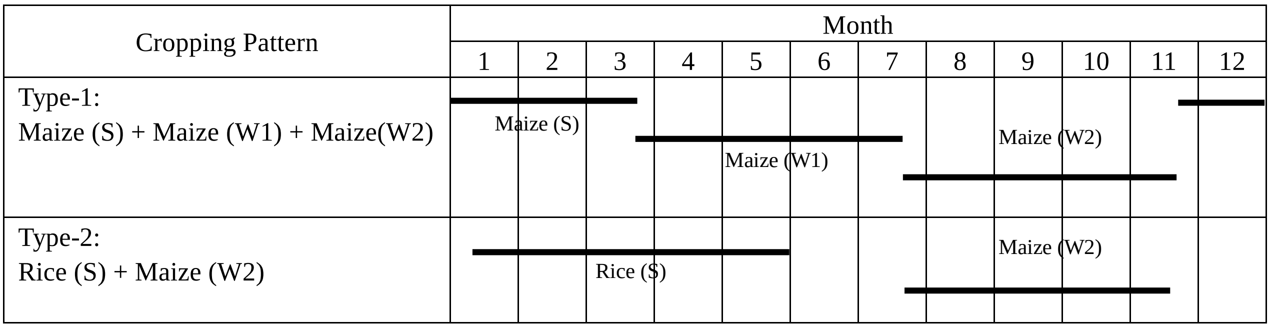
Meteorological Stations by Agricultural Development Division

ADD	Northern Area		Central Area		Southern Area	
	Stations	Eleva. (m)	Stations	Eleva. (m)	Stations	Eleva. (m)
Karonga	Chitipa	EL. 1,285	Karonga	EL. 529		
Mzuzu	Bolero	EL. 1,100	Mzuzu	EL. 1,250	Mzimba	EL. 1,349
			Khata Bay	EL. 500		
Kasungu			Kasungu	EL. 1,058		
Salima			Nkhotakota	EL. 500	Salima	EL. 512
Lilongwe	Lilongwe	EL. 1,135	Dedza	EL. 1,632		
	Chileka	EL. 767				
	Chitedze	EL. 1,149				
Machinga	Monkey Bay	El. 482	Mangochi	EL. 482		
Blantyre					Thyolo	EL. 820
					Mulanje	EL. 612
					Mimosa	EL. 652
Shire Valley	Bvumbwe	El. 1,146	N'gabu	EL. 104		

(2) Proposed Cropping Patterns

Following **cropping** patterns are planned as a representative one in each area to calculate crop water requirements and irrigation water requirements, considering topography, water availability, soil conditions, current farming practices, marketing conditions, etc. around each areas

Proposed Representative Cropping Pattern in Eight ADD



(3) Estimation of Irrigation Water Requirements

In estimating irrigation water requirements applying the "CROPWAT" equation mentioned above, following procedures and assumptions are taken into considerations;

Crop coefficient : Crop coefficients for maize and upland crop are referred to the authorized values in the computer program, while those for paddy rice are quoted from FAO Technical paper NO. 24 (refer to **Figure A.2-1 and A.2-2** in the Attached Data)

Effective rainfall : Upland Crops

Effective rainfall for the upland crop is counted in calculating irrigation water requirement. Following UDDA Soil Conservation Service method (USSCS) will be applied to estimate an effective rainfall;

Effective rainfall/month = monthly rainfall (R) x (125 – 0.2 x R) / 125 for R < 250 mm
Effective rainfall/month = 125 + 0.1 x R for R > 250 mm

Paddy Rice

Effective rainfall for paddy rice was estimated based on the following criteria;

10-day rainfall (R10) < 10 mm : 0 %
R10 < (N +LP) x 10 day : 100 %
R10> (N +LP) x 10 day : (N+ LP) x 10 day x100/R10
Where : N : Nursery water
LP : Land preparation water

Irrigation efficiency (IE) : Following irrigation efficiencies will be used.

Items	Upland Crops	Paddy Rice
Application Efficiency	70 %	80 %
Canal Efficiency (Main/Lateral)	90 %	90 %
(Farm Ditch)	80 %	80 %
Overall Irrigation Efficiency	50 %	58 %

Net irrigation water requirements (NWR):

Net irrigation water requirements (NWR) will be calculated by deducting the effective rainfall estimated on the 10-day basis by following equation;

NWR = ETc - Re

Where;

NWR : Net irrigation requirements (mm/day)
ETc : Crop evapo-transpiration (mm/day)
Re : Effective rainfall (mm)

Gross irrigation water requirements (GWR):

Gross irrigation water requirements (GWR) will be calculated by taking into consideration overall irrigation efficiencies (IE). The GWR will be estimated by the following equation.

GWR= NIR/IE

Where;

GWR : Gross irrigation water requirements (mm/day)
NWR : Net irrigation water requirements (mm/day)
IE : Overall irrigation efficiency

Table A.2-2 in the Attached Data shows the major dimensions for 18 station-wised cropping patterns covering eight ADD. 10-day interval of irrigation water requirements will be calculated at the 18 stations based on the above mentioned procedures and pre-conditions, and their results are summarized **Table 4-2**.

(4) Irrigation Water Requirements for System Capacity

Irrigation water requirements (IWR) to plan the system capacity will be determined by taking into consideration the time of irrigation hours per day and working day per week. The following equation will be used for the determination of the IWR:

IWR = GWR x A x 10,000 /(Hr x 3,600) x 7/v

Where,

IWR : Irrigation water requirements for system capacity (lit./sec)
GWR : Gross irrigation water requirements (mm/day)
A : Irrigation area (ha)
Hr : Water supply hours per day (hrs)
V : Working days per week (days)

Table 4-2 Results of Estimated Irrigation Water Requirements at Representative Meteorological Stations in Eight ADDs

(unit : lit/sec/ha)

ADD	Meteorological Station 1/	Cropping Pattern	Jan.			Feb.			Mar.			Apr.			May			June			July			Aug.			Sept.			Oct.			Nov.			Dec.		
			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	
1. Karonga	Chitipa	Type-1	0	0	0	0	0	0	0	0	0	0	0	0.38	0.61	0.81	0.99	1.05	1.09	1.14	1.17	1.01	0.34	0.34	0.41	0.69	1.02	1.36	1.66	1.71	1.72	1.70	1.63	1.02	0	0	0	0
	Karonga	Type-1 + Type-2	0.09	0.20	0.32	0.27	0.23	0.14	0.18	0.18	0	0	0	0	0.06	0.45	0.71	0.72	0.74	0.75	0.75	0.63	0.29	0.30	0.35	0.58	0.85	1.13	1.39	1.44	1.46	1.46	1.37	0.91	0	0	0	0
2. Mzuzu	Bolero	Type-1	0	0	0	0	0	0.02	0.08	0.04	0	0	0.04	0.39	0.69	0.95	1.16	1.22	1.26	1.30	1.30	1.10	0.36	0.36	0.41	0.67	0.95	1.24	1.47	1.48	1.45	1.40	1.32	0.86	0	0	0	0
	Mzuzuz	Type-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14	0.23	0.32	0.41	0.48	0.46	0.14	0.20	0.25	0.43	0.62	0.80	0.95	0.94	0.90	0.85	0.75	0.45	0	0	0	0
	Nkhata Bay	Type-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	0.44	0.59	0.76	0.85	0.85	0.67	0.15	0.23	0.32	0.54	0.80	1.07	1.30	1.30	1.28	1.21	1.02	0.57	0	0	0	0
	Mzimba	Type-1	0	0	0	0	0	0	0	0	0	0	0	0.32	0.60	0.80	0.97	1.02	1.06	1.10	1.12	0.96	0.32	0.34	0.39	0.65	0.96	1.29	1.57	1.63	1.64	1.62	1.39	0.88	0	0	0	0
3. Kasungu	Kasung	Type-1	0	0	0	0	0	0	0.09	0.10	0	0	0.22	0.53	0.75	1.02	1.23	1.28	1.30	1.31	1.29	1.07	0.34	0.34	0.38	0.62	0.88	1.13	1.34	1.35	1.32	1.27	1.06	0.56	0	0	0	0
4. Salima	Nkhotakota	Type-1 + Type-2	0	0.07	0.07	0.15	0.15	0.16	0.17	0.17	0	0	0	0	0.15	0.62	0.90	0.93	0.97	0.99	0.99	0.83	0.38	0.39	0.44	0.71	1.01	1.31	1.55	1.56	1.54	1.48	1.30	0.66	0	0	0	0
	Salima	Type-1	0	0	0.14	0.12	0.10	0.11	0.14	0.04	0	0	0.05	0.43	0.70	0.94	1.12	1.16	1.16	1.21	1.20	1.02	0.33	0.35	0.40	0.67	0.98	1.31	1.58	1.52	1.50	1.50	1.36	0.9	0	0	0	0
5. Lilongwe	Chileka	Type-1	0	0	0.15	0.14	0.13	0.14	0.15	0.04	0	0	0	0.24	0.50	0.70	0.82	0.83	0.84	0.86	0.86	0.73	0.24	0.26	0,30	0.51	0.76	1.02	1.26	1.26	1.24	1.18	1.02	0.63	0	0	0	0
	Lilongwe	Type-1	0	0	0	0	0	0.03	0.07	0.01	0	0	0	0.25	0.51	0.70	0.84	0.86	0.88	0.90	0.91	0.78	0.26	0.27	0.32	0.54	0.80	1.07	1.33	1.39	1.42	1.42	1.24	0.74	0	0	0	0
	Dedza	Type-1	0	0	0	0	0	0	0	0	0	0	0	0.15	0.45	0.66	0.79	0.82	0.84	0.86	0.87	0.75	0.25	0.26	0.31	0.52	0.77	1.04	1.29	1.35	1.38	1.37	1.28	0.77	0	0	0	0
6. Machinga	Monkey Bay	Type-1	0	0	0	0.02	0.09	0.20	0.33	0.31	0	0	0.08	0.45	0.78	1.07	1.30	1.35	1.38	1.40	1.39	1.16	0.40	0.40	0.45	0.73	1.04	1.34	1.58	1.69	1.56	1.51	1.43	1.00	0	0	0	0
	Mangochi	Type-1 + Type-2	0.08	0.10	0.12	0.07	0.10	0.17	0.38	0.34	0	0	0.06	0.32	0.55	0.75	0.91	0.95	0.97	0.98	0.97	0.81	0.37	0.38	0.43	0.70	1.00	1.30	1.55	1.58	1.56	1.50	1.30	0.82	0	0	0	0.11
7. Blantyre	Thyolo	Type-1	0	0	0.03	0.01	0	0	0	0	0	0	0	0	0.13	0.36	0.56	0.63	0.63	0.60	0.55	0.40	0	0.15	0.28	0.48	0.73	1.00	1.21	1.13	1.11	1.16	1.02	0.53	0	0	0	0
	Mulanje	Type-1 + Type-2	0	0.08	0.08	0.15	0.16	0.16	0.16	0.16	0.17	0.08	0.08	0.08	0.23	0.12	0.22	0.18	0.23	0.31	0.39	0.38	0.20	0.21	0.24	0.37	0.51	0.64	0.77	0.77	0.73	0.68	0.57	0.26	0	0	0	0
8. Shire Valley	Bvumbwe	Type-1 + Type-2	0.08	0.08	0.08	0.15	0.15	0.16	0.05	0.05	0.06	0.25	0.25	0.25	0.49	0.49	0.65	0.49	0.49	0.46	0.41	0.31	0.03	0.16	0.26	0.44	0.66	0.89	1.08	1.06	1.03	0.96	0.78	0.38	0	0	0	0.04
	Ngabu	Type-1	0	0.14	0.34	0.35	0.34	0.35	0.34	0.20	0	0	0.03	0.39	0.71	1.02	1.22	1.27	1.29	1.28	1.24	1.03	0.29	0.37	0.45	0.75	1.1	1.45	1.73	1.63	1.64	1.71	1.57	1.00	0	0	0	0

Note : Detail calculations are given in Table A.2-3 in the Attached Data.

1/: Refer to Figure 4-3.

Data-1: Manual for CROPWAT 4 Windows Computer Software

1. Outline of CROPWAT 4 Windows Computer Software

In the process for estimating the irrigation water requirements, the reference crop evapo- transpiration (ETo) for maize and upland crops can be estimated using the "**CROPWAT 4 for Windows Computer Software"**, being popular in the agricultural development plan in Malawi, which is based on the FAO Penman- Monteich Equation. The Penman-Monteith equation is given by the following equation

$$ETo = \frac{0.408\,\Delta(Rn - G) + \gamma \frac{900}{T + 273} U2(es - ea)}{\Delta + \gamma(1 + 0.34u2)}$$

Where;

ETo	=	Reference evapo-transpitation (mm/day)
Rn	=	Net radiation at the crop surface (MJ/m^{2}per day)
G	=	Soil heat flux density (MJ/m^{2}per day)
T	=	Mean daily air temperature at 2 m height (℃)
U2	=	Wind speed at 2 m height (m/sec)
Es	=	Saturation vapour pressure (kpa)
Ea	=	Actual vapour pressure (kpa)
Es – ea	=	Saturation vapour pressure deficit (pka)
△	＝	Slope of saturation vapor pressure curve at temperature T (kpa/℃)
γ	=	Psychometric constant (kpa/℃)

Crop water requirements (ETc/CWR) can be estimated by multiplying ETo mentioned in the above by a crop coefficient (Kc), that is:

ETc = ETo x Kc

Where;

ETc /CWR	=	Crop water requirements (mm/day)
ETo	=	Reference crop evapo-transpiration (mm/day)
Kc	=	Crop coefficient

2. Installation of "CROPWAT 4 Windows Computer Software"

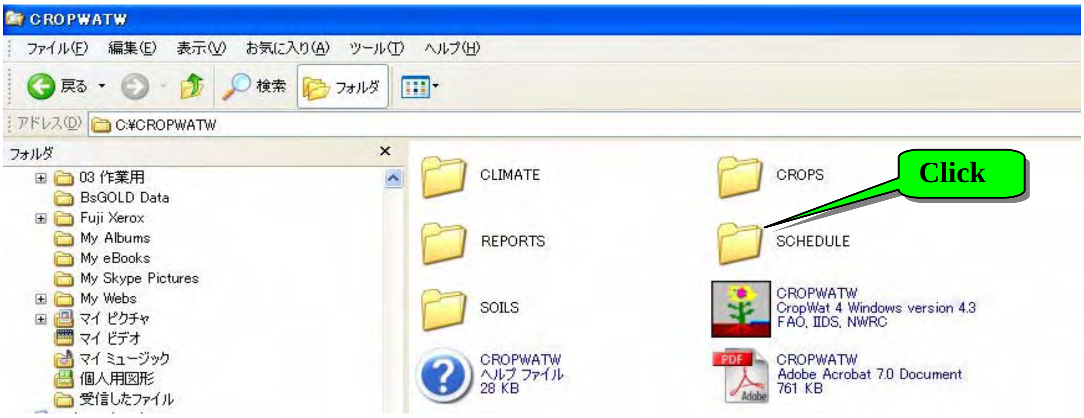
"CROPWAT 4" Software application is installed by the following ways;

a) Set-up CD on the CD drive, and then open the **Cropwat unzipped** folder,
b) Double click on the file called **setup.exe**, and follow the on-screen instruction,
c) Create a folder on the C : drive called **Cropwat Files,**
d) Copy all the files from **Cropwat/Africa files unjipped** to the newly created **Cropwat Files** folder,
e) Launch **Cropwat**,
f) When wanting to retrieve data, navigate to the **Cropwat Files** folder, and choose the relevant country file,

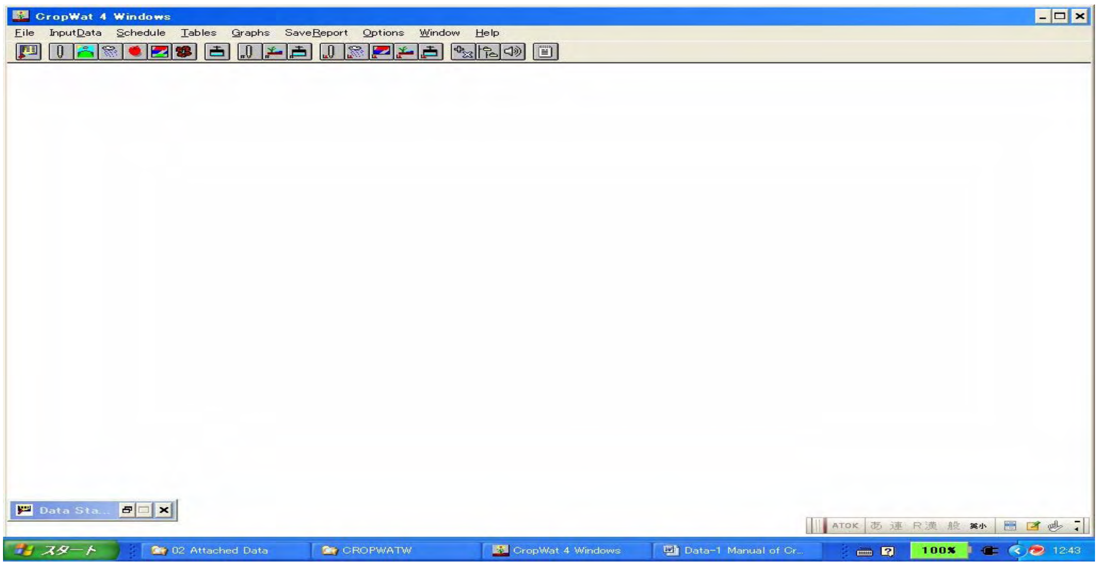
3. Interface and Menu Systems

a) Click **My-computer**, and then select **Drive C**,

b) Click **CROPWAT**, and then double click “**CROPWAT Cropwat 4 Windows”**,



c) Cropwat for Windows main screen appears as follows,



d) Main Menu and Tool Bar

The main “route” through the program follows the menu options along the top of the screen, and also you can access the data entry windows using the icons in the **Tool Bar**.

1) First, you enter data (either using menu option **File** or **Input Data**)
2) Next, you define your scheduling criteria (use menu option **Schedule**, **Criteria**),
3) The results can be seen in tabular or graphical form (menu options **Tables** and **Graphs**)
4) You can save the results into ASCII file

4. Actual Operation of CROPWAT 4 Windows Computer Software

4.1 Data needed for Calculation

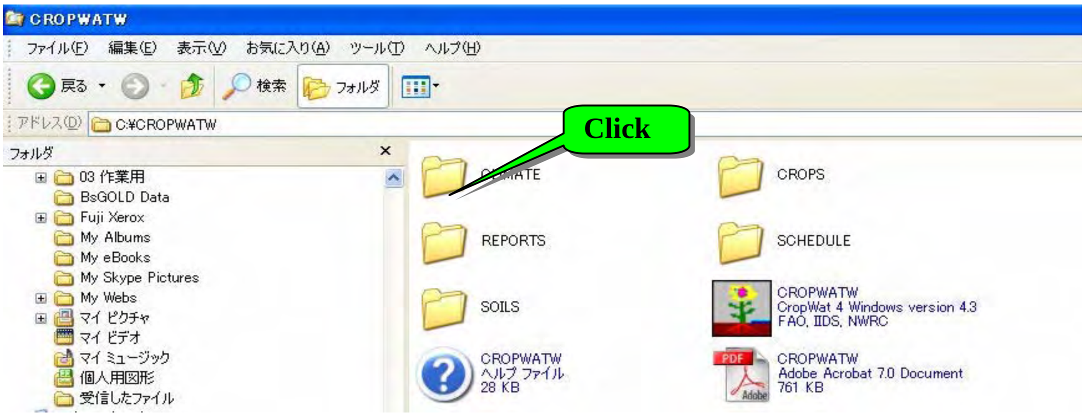
Following data required for Crop Water Requirements and Scheduling calculation have to be prepared in advance;

- **Climate data** consisting of temperature, wind speed, actual sunshine hours, humidity (refer to **Table A.2-1**)
- **Cropping pattern** consisting of one or more crop file names, planting date (sowing, transplanting, harvesting date, growing periods), and rate of cropping area (refer to **Table A.2-2**),
- **Monthly rainfall** data at the observation station
- **Soil type information** consisting of soil texture, rooting depth, readily available soil moisture (refer to **Table A.2-2**).

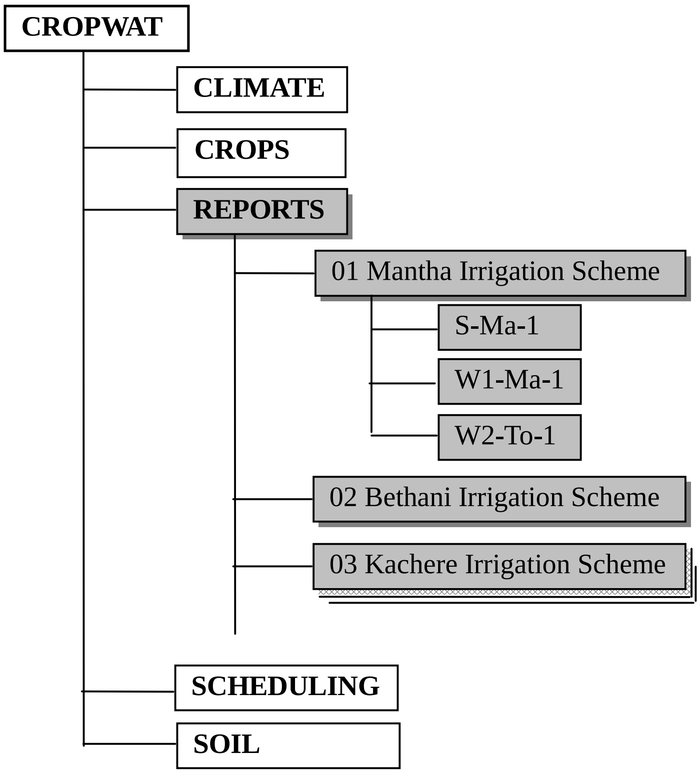
4.2 Creation of Folders to save Calculation Results

Prior to the calculation, necessary **Folders** to save calculation results for each irrigation scheme have to be created in the **Reports of Cropwat Files,**

a) Click **Cropwat** in drive **C**, and then double click **Reports**,



b) Create scheme-wised **Folders**

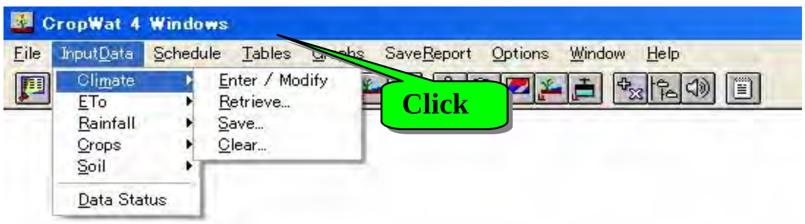


4.3 Calculation of Crop Water Requirements and Scheduling

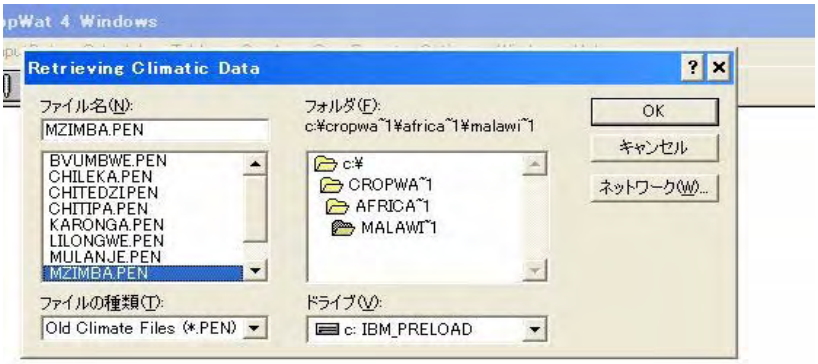
a) Climate

By Means of Retrieve Way (in Case Climate Database is available in Cropwat Software)

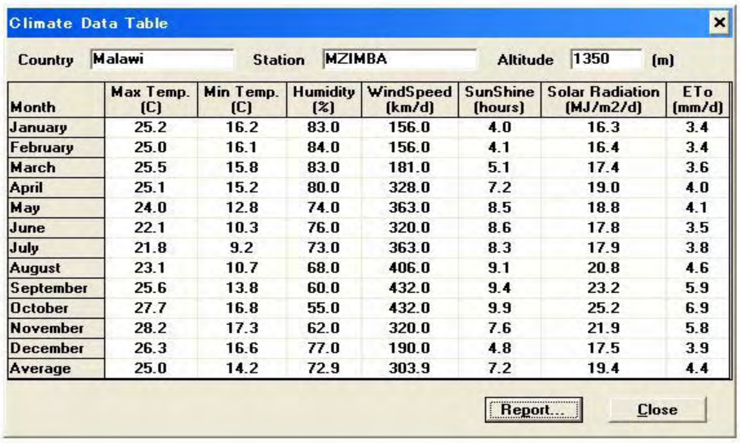
1. Open **CROPWAT, Cropwat 4 Windows**
2. **Input Data** (click) → **Climate** (click) → **Retrieve** (click)



3. **C:¥** (double click) → **CROPWA~1** (double click) **AFRICA~1** (double click) → **MALAWI** (double click)
4. **"List Files of Type ▼"**(click) → select "**Old Climate File (*.pen)**" → Present the Climate Stations in **File Name** → Select the objective station (**MUZIMBA.PEN**) → **Ok**



5. Present **"Any ETo data currently in memory will be cleared"** → **Ok**
6. **Tables** (click) → **Climate & ETo** (click) → Present "**Climate Data Table**" → **Report**



Climate Data Table

Country: Malawi Station: MZIMBA Altitude: 1350 (m)

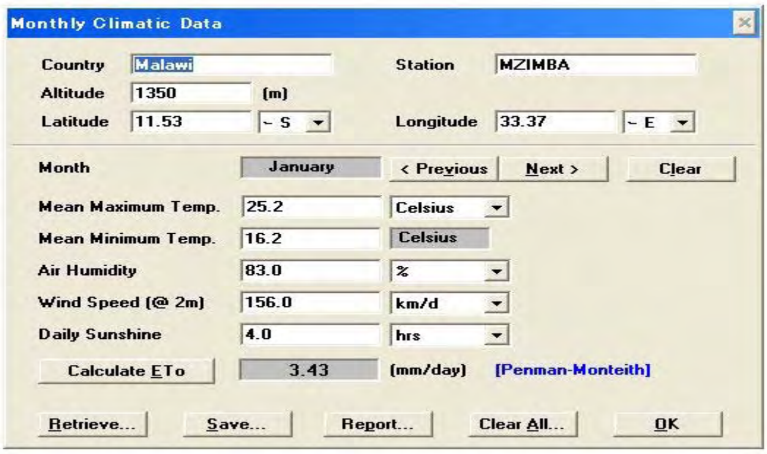
Month	Max Temp. (C)	Min Temp. (C)	Humidity (%)	WindSpeed (km/d)	SunShine (hours)	Solar Radiation (MJ/m2/d)	ETo (mm/d)
January	25.2	16.2	83.0	156.0	4.0	16.3	3.4
February	25.0	16.1	84.0	156.0	4.1	16.4	3.4
March	25.5	15.8	83.0	181.0	5.1	17.4	3.6
April	25.1	15.2	80.0	328.0	7.2	19.0	4.0
May	24.0	12.8	74.0	363.0	8.5	18.8	4.1
June	22.1	10.3	76.0	320.0	8.6	17.8	3.5
July	21.8	9.2	73.0	363.0	8.3	17.9	3.8
August	23.1	10.7	68.0	406.0	9.1	20.8	4.6
September	25.6	13.8	60.0	432.0	9.4	23.2	5.9
October	27.7	16.8	55.0	432.0	9.9	25.2	6.9
November	28.2	17.3	62.0	320.0	7.6	21.9	5.8
December	26.3	16.6	77.0	190.0	4.8	17.5	3.9
Average	25.0	14.2	72.9	303.9	7.2	19.4	4.4

Report... Close

7. Present "**Saving Climate & ETo Data in a Formatted File**" → **Mantha Scheme** in **Directories** (double click) → Selection of **S-Ma-1** folder → Input **Climate. txt** in the space of **"＊".txt in File Name** → **OK**
8. Present "**Data saved successfully in C:¥Cropwatw ¥Report ¥ 01 Mantha ¥Climate.txt** → **OK**
9. **Close** (click)

<u>By Means of Data Input Way (in Case Climate Database is not available in Cropwat Software)</u>

1. Open **CROPWAT, Cropwat 4 Windows**
2. Click **Input Data** (click) → **Climate** (click) → **Enter/Modify** (click)
3. Present "**Monthly Climate Data**" → Input **Climate Data** in January → **Next** (click) → Input Data up-to December → **Save**

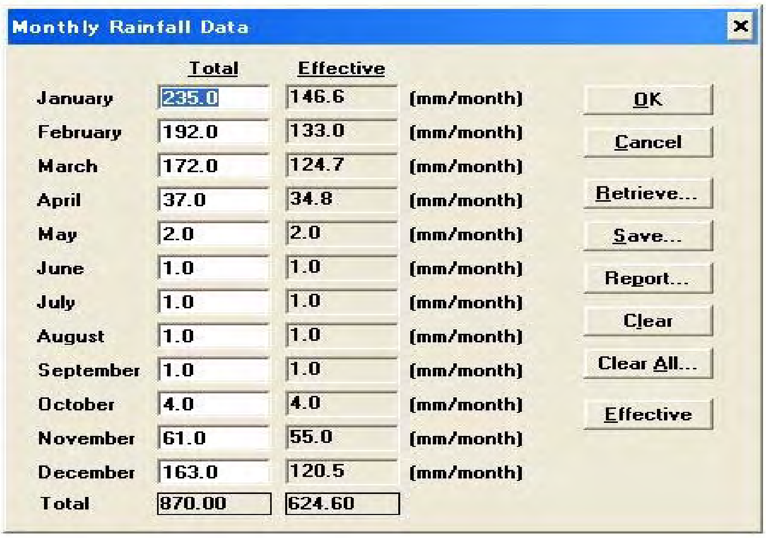


4. Present "**Data saved successfully in C: ¥Cropwatw ¥Climate ¥Kasungu.pem**"
5. Present "**Saving Climate Data**" → Input **Kasungu. Pen** in **File Name** → **OK** → **Ok**
6. **Table** (click) → **Climate & ETo** (click) → Present **Climate & ETo** → **Report** (click)
7. Present "**Saving Climate & ETo Data in a Formatted File**" → **Kachere Scheme in Directories** (double click) → Select **S-Ma-1** folder → Input **Climate. txt** in the space of "**＊".txt** → **OK** → **Close**

b) Rainfall

By Means of Retrieve Way (in Case Climate Database is available in Cropwat Software)

1. **Input Data** (click) → **Rainfall** (click) → **Retrieve** (click)
2. **C:¥** (double click) → **CROPWA~1** (double click) → **AFRICA~1** (double click) → **MALAWI** (double click)
3. **"List Files of Type ▼"** (click) → **select "Old Rainfall File.cli (＊.Cli)"** → Present **the Rainfall Stations in File Name** → Select **the objective station (Muzimba.Cli)** → **Ok**
4. **Table** (click) → **Rainfall** (click) → present "**Monthly Rainfall Data**" → **Report** (click)



5. Present "**Saving Rainfall Data in a Formatted File**" → **Mantha Scheme** in **Directories**

(double click) → Select "**S-Ma-1**" folder → Input "**Rain.txt**" in the space of "＊".txt → **Ok**

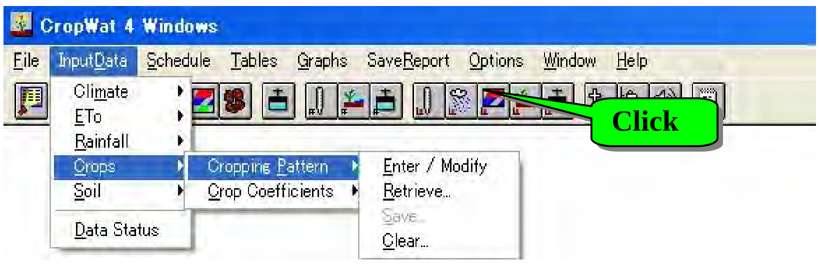
6. Present "**Data saved Successfully in C: ¥Cropwatw ¥01 Mantha ¥Rain.txt** → **OK**
7. **Close** (click)

<u>By Means of Data Input Way (in Case Climate Database is not available in Cropwat Software)</u>

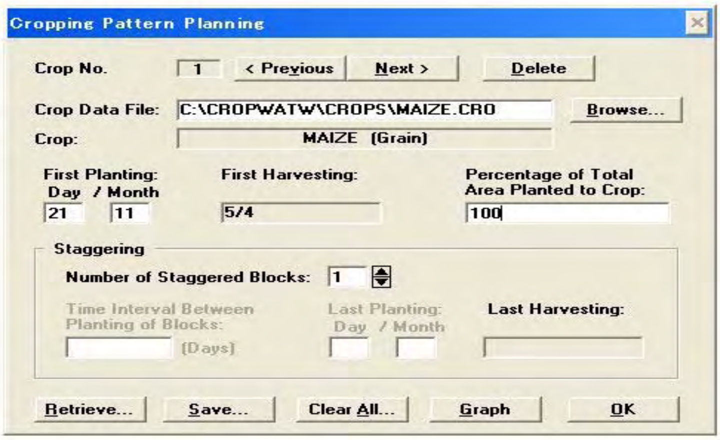
1. **Input Data** (click) → **Rainfall** (click) → **Enter/Modify** (click)
2. Present "**Monthly Rainfall Data Form**" → Input **Monthly Rainfall Data** → Automatically converted into **Effective Rainfall** → **Save** (click)
3. Present "**Saving Rainfall Data**" → Input **Kasungu.crm** in **File Name** → **OK** → **OK**
4. **Table** (click) → **Rainfall** (click) → Present **Monthly Rainfall Data** → **Report** (click)
5. Present "**Saving Rainfall Data in a Formatted File**" → **Kachere Scheme in Directories** (double click) → Selection of **S-Ma-1** folder → Input **Rain. txt** in the space of ＊**.txt** → **OK** → **Close** (click X)

c) Crops – Cropping Pattern

1. **Input Data** (click) → **Crops** (click) → **Cropping Pattern** (click)→ **Enter/Modify** (click)



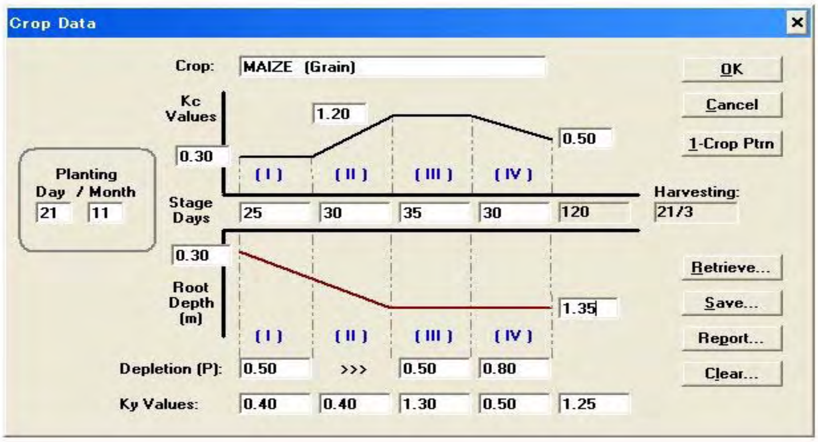
2. Present **"Cropping Pattern Planning"** → **Browse Crop Data File** (click) → **Select Crop (Exa. MAIZE. CRO)** in **Retrieve Crop Data** → **OK**
3. Input **First Planting Date Day** [21] / **Month** [11] → Input **Percentage of Total Area Planted to Crop** [100] → **OK**



4. **Save Report** (click) → **Cropping Pattern** (click) → **Mantha** in **Directories** (double click) → **S-Ma-1** (double click)
5. Present "**Saving Cropping Pattern Data in a Formatted File**" → Input **Croppat.txt** in **File Name** → **OK** → **OK**
6. **Close** (click X)

d) Crops – Crop Coefficient

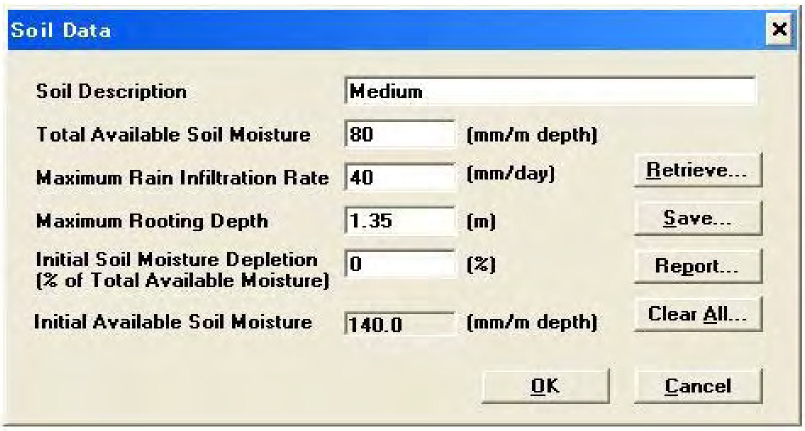
1. **Input Data** (click) → **Crops** (click) → **Cropping Coefficient** (click) → **Enter/Modify** (click)
2. Present "**Crop Data"** → Input **Planting Day** **21** / **Month** **11**
3. Change "**Stage Days"** → (I) **25** (II) **30** (III) **35** (IV) **30**
4. Change "**Root Depth"** **1.35**



5. **Report** (click) → Present "**Saving Crop Data in a Formatted File"** → **Mantha** (double click) → **S-Ma-1** (double click)
6. Present "**Saving Crop Data in a Formatted File**" → Input **Cropcoef.txt in File Name** → **OK** → **OK**
7. **Close** (click X)

e) Soil

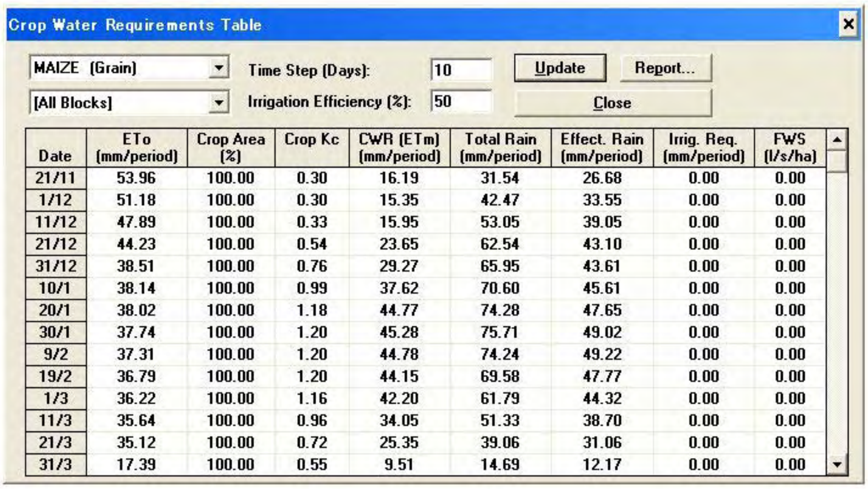
1. **Input Data** (click) → **Soil** (click) → **Enter/Modify** (click)
2. Present "**Soil Data"** → **Retrieve** (click)
3. Present "**Retrieve Soil Data**" → **Medium** (click) → **OK**
4. Present "Soil Data" → Change "**Total Available Soil Moisture**" → **80**
5. Change "**Maximum Rooting Depth**" → **1.35**



6. **Report** (click) → Present "**Saving Soil Data in a Formatted File**" → "**Mantha"** (double click) → **"S-Ma-1"(**double click**)**
7. Present "**Saving Soil Data in a Formatted File**" → Input "**Soil.txt in File Name"** → **OK** → **OK**
8. **Close** (click X)

f) Crop Water Requirement (CWR)

1. **Table** (click) → **CWR** (click) → Present "**Crop Water Requirement Table**"
2. Change "**Time Step (days)**" → **10**
3. Change "**Irrigation Efficiency**" → **50**



Crop Water Requirements Table

MAIZE (Grain) | Time Step (Days): 10 | Update | Report...

[All Blocks] | Irrigation Efficiency (%): 50 | Close

Date	ETo (mm/period)	Crop Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irrig. Req. (mm/period)	FWS (l/s/ha)
21/11	53.96	100.00	0.30	16.19	31.54	26.68	0.00	0.00
1/12	51.18	100.00	0.30	15.35	42.47	33.55	0.00	0.00
11/12	47.89	100.00	0.33	15.95	53.05	39.05	0.00	0.00
21/12	44.23	100.00	0.54	23.65	62.54	43.10	0.00	0.00
31/12	38.51	100.00	0.76	29.27	65.95	43.61	0.00	0.00
10/1	38.14	100.00	0.99	37.62	70.60	45.61	0.00	0.00
20/1	38.02	100.00	1.18	44.77	74.28	47.65	0.00	0.00
30/1	37.74	100.00	1.20	45.28	75.71	49.02	0.00	0.00
9/2	37.31	100.00	1.20	44.78	74.24	49.22	0.00	0.00
19/2	36.79	100.00	1.20	44.15	69.58	47.77	0.00	0.00
1/3	36.22	100.00	1.16	42.20	61.79	44.32	0.00	0.00
11/3	35.64	100.00	0.96	34.05	51.33	38.70	0.00	0.00
21/3	35.12	100.00	0.72	25.35	39.06	31.06	0.00	0.00
31/3	17.39	100.00	0.55	9.51	14.69	12.17	0.00	0.00

4. **Report** (click) → Present "**Saving CWR Data in a Formatted File**" → "**Mantha"** (double click) → "**S-Ma-1"** (double click)
5. Present "**Saving CWR Data ub a Formateted File**" → Input "**FWS.txt in File Name**"→ **OK** → **OK**
6. **Close** (click)

g) Print Out the Calculated Data

1. Click **My-Computer**, and then select **Drive C**
2. Double Click "**CROPWAT"**
3. **Report** (click) → Select "**Mantha**" → Select "**S-Ma-1**"
4. Present "**Each File of Climate, Rain, Croppat, Cropcoef, Soil, CWR**"
5. Print out **Each File**

Calculated Crop Water Requirements (CWR)

FWS

2008/05/07 CropWat 4 Windows Ver 4.3

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Crop Water Requirements Report

****

- Crop # 1 : MAIZE (Grain)
- Block # : [All blocks]
- Planting date : 21/11
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 50%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				----------	(mm/period)	----------		
21/11	53.96	100.00	0.30	16.19	31.54	26.68	0.00	0.00
1/12	51.18	100.00	0.30	15.35	42.47	33.55	0.00	0.00
11/12	47.89	100.00	0.33	15.95	53.05	39.05	0.00	0.00
21/12	44.23	100.00	0.54	23.65	62.54	43.10	0.00	0.00
31/12	38.51	100.00	0.76	29.27	65.95	43.61	0.00	0.00
10/1	38.14	100.00	0.99	37.62	70.60	45.61	0.00	0.00
20/1	38.02	100.00	1.18	44.77	74.28	47.65	0.00	0.00
30/1	37.74	100.00	1.20	45.28	75.71	49.02	0.00	0.00
9/2	37.31	100.00	1.20	44.78	74.24	49.22	0.00	0.00
19/2	36.79	100.00	1.20	44.15	69.58	47.77	0.00	0.00
1/3	36.22	100.00	1.16	42.20	61.79	44.32	0.00	0.00
11/3	35.64	100.00	0.96	34.05	51.33	38.70	0.00	0.00
21/3	35.12	100.00	0.72	25.35	39.06	31.06	0.00	0.00
31/3	17.39	100.00	0.55	9.51	14.69	12.17	0.00	0.00
Total	548.15			428.12	786.82	551.50	0.00	[0.00]

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

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C:¥CROPWATW¥REPORTS¥01MANT~1¥S-MA-1¥FWS.TXT

h) Collection Ways for Inputed Data

1. Click **My-Computer**, and then select **Drive C**
2. Open **CROPWAT**, “**CROPWAT Cropwat 4 Windows”**
3. **Input Data** (click) → **Climate** (click) → **Enter/Modify** (Click) → **Retrieve** (click) → Select “**Kasungu**” → **OK**
4. Present “**Confirm Action Table**”, and “Any ETo data currentlt in memory will be cleared” → **OK**
5. **Next** (click) → **Collection of Input Data** → **Report** (click)
6. Select “**Kasungu**” and “**S-Ma-1**” → Put “**File Name (Climate. Txt)”** → OK
7. Inquireing “**Overwrite ?**” → “**Yes**” → **OK**